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# Strong-Motion Records at Army Hospitals in California From the Loma Prieta Earthquake of 17 October 1989

by
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Since 1982 the U.S. Army Construction Engineering Research Laboratory (USACERL) has maintained strong-motion seismic recording systems to measure ground motions and the resulting responses of representative engineered Army structures during strong local earthquakes. Two of these systems are installed in the Army hospitals on Presidio of San Francisco and at Fort Ord, CA.

On 17 October 1989 a major seismic event, the Loma Prieta earthquake, occurred near these California-based strong-motion systems. Data from the Loma Prieta earthquake are published in this report. Also included is information about the seismic instrumentation systems that gathered the data, the hospitals in which the systems are installed, and a summary of the damage observed to those structures.

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Since 1982 ~~the~~ U.S. Army Construction Engineering Research Laboratory (USACERL) has maintained strong-motion seismic recording systems to measure ground motions and the resulting responses of representative engineered Army Structures during strong local earthquakes. Two of these systems are installed in the Army hospitals on Presidio of San Francisco and at Fort Ord, CA.

On 17 October 1989 a major seismic event, the Loma Prieta earthquake, occurred near these California-based strong-motion systems. Data from the Loma Prieta earthquake are published in this report. Also included is information about the seismic instrumentation systems that gathered the data, the hospitals in which the systems are installed, and a summary of the damage observed to those structures. Keywords: Army facilities/hospitals; Earthquakes/damage assessment; Earthquake engineering; Accelerometers; Seismic waves/data; Faults geology; Soil structure interactions; Structural engineering; (over)

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## FOREWORD

This work was performed for Headquarters, U.S. Army Corps of Engineers (HQUSACE) under Operations and Maintenance, Army (OMA) project "Operation Maintenance and Data Reduction of Seismic Instrumentation Systems." The HQUSACE technical monitor was Mr. Charles Gutberlet, Jr., CEMP-ET.

The work was conducted by the Engineering and Materials (EM) Division of the U.S. Army Construction Engineering Research Laboratory (USACERL). Dr. Paul Howdyshell is Acting Chief of EM. The USACERL technical editor was Gordon L. Cohen, Information Management Office.

Appreciation is expressed to Mr. George Matsumura, CEMP-ET (retired), who initiated the Army's Strong-Motion Instrumentation Program and was the past technical monitor for this project.

COL Everett R. Thomas is Commander and Director of USACERL. Dr. L.R. Shaffer is Technical Director.

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CONTENTS

## FIGURES

## FIGURES (Cont'd)



## TABLES

**STRONG-MOTION RECORDS AT ARMY HOSPITALS IN CALIFORNIA FROM THE LOMA PRIETA EARTHQUAKE OF 17 OCTOBER 1989**

# 1 INTRODUCTION

## Background

The U.S. Army Construction Engineering Research Laboratory (USACERL) maintains seismic instrumentation systems it installed in three Army hospitals in the United States. Two of the systems are located in California — one at Letterman Army Medical Center (LAMC), Presidio of San Francisco, and one at Hays Army Community Hospital (HACH), Fort Ord. The third system is installed at Blanchfield Army Community Hospital, Fort Campbell, KY. These instrumentation systems are maintained by USACERL with assistance as needed from installation personnel.

The primary purpose of the Army building seismic instrumentation program is to record ground motions and the resulting responses of representative engineered structures during strong local earthquakes. Such an earthquake occurred in California on 17 October 1989.

The Department of the Interior U.S. Geological Survey (USGS) reported that this seismic event, referred to as the Loma Prieta earthquake, struck at approximately 1704 Pacific Daylight Time with a surface wave magnitude ($M_S$) of 7.1 on the Richter scale. It was centered about 10 mi (16 km) northeast of Santa Cruz, CA, at an hypocentral depth of approximately 11.5 mi (18.5 km). It was the largest magnitude earthquake centered in northern California since 1906. It caused at least 62 deaths, more than 3000 injuries, and up to $10 billion in property damage to the greater San Francisco Bay area.[1]

## Objective

The objective of this phase of the research was to document and publish data obtained from the California-based seismic instrumentation systems from the 17 October main shock of the Loma Prieta earthquake. The main shock triggered the systems at both LAMC and HACH. Two aftershocks were also recorded at HACH.

## Approach

This report documents Loma Prieta earthquake data collected by the previously specified seismic instrumentation stations. To provide a context for this data, a brief description of each hospital structure, the underlying geologies, and the instrumentation systems is provided, as is a brief summary of the buildings' structural response to the earthquake. Figures show the location of the instrumentation plans on each floor of the two buildings. Accelerograms of ground motion and structural response are provided for the two structures. Additional strong-motion information related to this earthquake is available from the USGS and the California Division of Mines and Geology, Office of Strong-Motion Studies, Sacramento, CA.

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[1] USGS Open File Report 89-568, *USGS Strong Motion Records From the Northern California (Loma Prieta) Earthquake of October 17, 1989* (USGS, October 1989).

## 2 HOSPITAL FACILITIES AND SITE INFORMATION

### Letterman Army Medical Center (LAMC)

LAMC is located about 1 mi (1.6 km) southeast of the Golden Gate Bridge. The epicenter of the Loma Prieta earthquake was approximately 60 mi (96 km) south-southeast of the hospital (see Figure 1).* The hospital, which was designed in the mid-1960s and occupied in 1968, is a 10-story reinforced concrete structure consisting of a base structure and a seven-story tower (see Figures 2 and 3). The base structure measures about 229 ft (70 m) in the transverse (north-south) direction and 350 ft (106 m) in the longitudinal (east-west) direction, and is three stories high. Plan dimensions of the tower vary with height: at the 4th and 5th floors it measures 247 ft (75 m) in the transverse direction and 108 ft (33 m) in the longitudinal direction; plan dimensions reduce to 175 ft (53 m) transversely by 108 ft (33 m) longitudinally for the 6th through the 10th floors (see Figures 4 and 5). The lateral resisting system of the building is composed primarily of reinforced concrete shear walls located in the core of the structure. Exterior precast walls form a pier and spandrel frame on each side of the building. A reinforced concrete waffle slab floor system serves as a rigid diaphragm at each story, transmitting forces horizontally to exterior and interior load-bearing walls and walls around the elevator shaft and stairwells. These walls carry the loads in shear to the cast-in-place concrete pile foundation.

According to a soil profile of the LAMC site,** the hospital is located on three distinct soil layers. The uppermost layer is 12 to 20 ft (3.5 to 6 m) deep and consists primarily of sandy clays and clayey sands. The intermediate layer extends 80 to 100 ft (24 to 30 m) below the surface and consists of nonplastic and compact silty sands. The lowest layer consists of lean and fat clays, clayey sands and sandy clays with some gravel and rock fragments; the overall depth to rock is estimated to vary from between 120 to 200 ft (36 to 60 m).

The major active faults of this area are part of the San Andreas system and include the San Andreas, Hayward, and Calaveras faults. The San Andreas fault is located 6 mi (10 km) west of LAMC; the Hayward and Calaveras faults are about 12 mi (20 km) northeast and 22 mi (35 km) northeast respectively at their closest points to the hospital. A 1973 report by an engineering consulting firm identified the San Andreas fault as the site's most likely source of a damaging earthquake. In this report a maximum probable earthquake of Richter magnitude 8.25, a causative fault distance of 6 mi (10 km) from the site, and a recurrence interval of 100 years was postulated to produce a peak horizontal ground acceleration of 0.5 g, with strong shaking lasting about 40 seconds.[2]

### Hays Army Community Hospital (HACH)

HACH is located 2 mi (3.4 km) inland from Monterey Bay, about 27 mi (44 km) south-southeast of the epicenter of the Loma Prieta earthquake (Figure 1). HACH is similar in design to LAMC and was completed in 1971. It is an eight-story reinforced concrete structure with a six-story tower (see Figures 6 through 9). Its lateral-force-resisting system, like that of LAMC, consists of rigid reinforced concrete

* Figures are presented beginning on p 15.

** This profile was compiled by the engineering consulting firm Aghabian Associates based on boring logs and soil test reports provided by the U.S. Army Corps of Engineers, Sacramento District.

[2] *Aseismic Design Criteria, Rehabilitation of Existing Hospital Facilities*, Task Report — Site-Dependent Maximum Probable Earthquake Criteria, Task 1 (Aghabian Associates, El Segundo, CA, October 1973).

diaphragms and reinforced concrete shear walls. The loads are transmitted to a spread footing foundation system.

The hospital site is underlain by more than 100 ft (30 m) of dune sand deposits consisting of firm to very dense sands and silty sand deposits. The deposits are uniformly fine grained, well sorted and semi-consolidated, and extend to slate rock and sandstone at depths greater than 300 ft (90 m).[3]

The principal onland faults in the region of Fort Ord are the San Andreas and the Sur-Nacimiento faults. These form the northeast and southwest boundaries, respectively, of the Salinian block, in which many fault traces occur. These include the Palo Colorado-San Gregorio fault, about 12 mi (20 km) southwest of HACH; the Tularcitos fault, 4 mi (6.4 km) southwest of HACH, which is the longest known fault in the region; the Monterey Bay fault; and the King City fault. The San Andreas, Palo Colorado-San Gregorio, and Monterey Bay fault zones are all seismically active. As with LAMC, the San Andreas is considered the controlling fault for a maximum probable 8.25-magnitude earthquake at HACH. A peak horizontal acceleration of 0.42 g, with strong shaking lasting about 40 seconds, was expected.[4]

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[3] *Aseismic Design Criteria.*

[4] *Aseismic Design Criteria.*

## 3 SEISMIC INSTRUMENTATION SYSTEMS AT LAMC AND HACH

LAMC and HACH are extensively instrumented. Sensor locations were designed to provide significant dynamic response data for a rigorous analysis of each host structure's performance during strong earthquake motions.

In 1982 USACERL instrumented both facilities with 18-channel strong motion digital cassette accelerograph systems manufactured by Terra Technology Corp. (see Figure 10). Each seismic instrumentation system (SIS) consists of a digital cassette accelerograph (DCA), a power supply with battery backup, and 18 servo accelerometers. A playback/plotter system is located at USACERL for processing data tapes, and data files may be transferred to USACERL computers for analysis.

In each hospital the SIS continually monitors three accelerometers—two horizontal and one vertical —which are mounted on the floor of the basement/crawlspace to measure base accelerations (Figure 11). These accelerometers also function as trigger mechanisms for each entire system. When these base outputs exceed a preset trigger level of 0.012 g peak, the DCA is activated. Additional accelerometers are positioned on upper floors (Figure 12) and located in stacks above one another so horizontal motions in the east-west and north-south directions may be captured. For example, LAMC accelerometers LC1, L41, L61, and LR1 (on Figures 13 through 17) represent a stack of instruments for collecting accelerations in the north-south direction. Similarly LC2, L42, L62, and LR2 monitor accelerations in the east-west direction. Several accelerometers are also located near the perimeter of the building floors; these are placed so torsional response of the building can be identified. Sensors LC5, L35, L34, L44, L45, L65, L66, and LR6 are examples of such instruments at LAMC.

At LAMC, accelerometers are located on the underside of the floor on the third, fourth, sixth, and roof levels. At HACH, accelerometers are on the underside of the floor at the fourth, sixth, seventh, and roof levels (Figures 18 through 22).

The DCA contains six digital cassette tape decks, each of which records output signals from three accelerometers with a digital resolution of 12 bits per channel. The accelerometers have a full-scale peak range of +/- 2 g. The signals are digitized and processed through a 0.64-second pre-event memory buffer before being recorded as a complete time history on tape at 100 samples per second per channel. The output signals from all accelerometers are continually monitored, digitized, and processed through the pre-event memory buffer, but are not recorded. When the system is triggered by the basement accelerometers, all of the tape decks begin recording data from the beginning of the pre-event buffers, so the resulting records include 0.64 seconds of information from before the trigger occurred. Recording continues for 15 seconds after the preset trigger level is last exceeded. Date, time (hours, minutes, seconds), DCA serial number, and event number are obtained from the unit's internal clock and recorded with the earthquake data. The battery backup assures continuous SIS operation for up to 30 hours if commercial power is interrupted or lost. Cables connect each accelerometer to the DCA, which supplies DC (direct current) power and calibration signals, and records the output signals from the accelerometers.

Cassette tapes from the DCA are played back on the playback/plotter system, which provides three-channel hardcopy charts of acceleration versus time. A computer interface transfers data to a microcomputer for storage, display, and analysis of seismic events.

SIS maintenance at each hospital site is performed annually by USACERL personnel. This includes operational checkout of each system, measuring accelerometer signal output and power supply voltages,

replacing worn tape deck parts, cleaning the tape heads, checking and resetting the clock, checking and replacing batteries, verifying system trigger operation, recording accelerometer calibration on tape, and loading fresh recording tapes -- the used ones are sent to USACERL for playback. Cable runs and accelerometer mounting locations are also checked for problems or damage. SIS operation and tape-change procedure is reviewed with hospital personnel. Such maintenance was performed at both facilities in August 1989. At the same time, the equipment manufacturer (Terra Technology) performed a complete checkout of the LAMC system.

The SIS systems have operated at the two hospitals in California for 8 years with a high degree of reliability. The main service requirement during this time has been maintaining the gel-cell rechargeable batteries in the battery back up system. Local hospital maintenance personnel have been employed to periodically check the system and alert USACERL to any potential problems.

## 4 STRUCTURAL RESPONSE OF HOSPITALS TO LOMA PRIETA EARTHQUAKE

The following is a summary of highlights of the data and observations related to the structural response of the two hospitals.

### Earthquake Records for LAMC

Earthquake records for LAMC are shown in Figures 23 through 28. The duration of strong ground motion at LAMC was approximately 5 seconds. The peak horizontal ground acceleration, as recorded on the crawlspace sensors at LAMC, was 0.16 g in the east-west direction; the peak vertical ground acceleration recorded there was 0.07 g. (The peak north-south horizontal ground acceleration at LAMC was 0.09 g.) The peak acceleration values for all LAMC locations are shown in Table 1.

A problem occurred in one tape deck at LAMC, which caused significant gaps in three of the acceleration records (Gages L34, L35, and LC5). It was not possible to interpret these data with any degree of confidence, but the records are included to provide information on peak accelerations in relation to the other floors of the hospital.

### Earthquake Records for HACH

Earthquake records for HACH are shown in Figures 29 through 33. The duration of strong ground motion was significantly longer at HACH than at LAMC — approximately 14 seconds. Ground accelerations were also greater at HACH, primarily due to its closer proximity to the epicenter. The peak horizontal ground acceleration recorded on the crawlspace sensors at HACH was 0.17 g in the east-west direction; the peak vertical ground acceleration there was 0.11 g. The peak north-south horizontal ground acceleration was 0.13 g. A summary of the accelerations recorded at all HACH locations are shown in Table 2.

**Table 1**

**Peak Accelerations Recorded at LAMC, 17 October 1989**

**SENSOR STACK**

| Floor | Center | | | North | South | East |
|---|---|---|---|---|---|---|
| | N-S | E-W | Vert | E-W | E-W | N-S |
| **Roof** | .46 | .45 | - | - | .57 | - |
| **6th Flr** | .27 | .20 | - | .25 | .23 | - |
| **4th Flr** | .19 | .15 | .13 | .20 | - | .18 |
| **3rd Flr** | - | - | - | .18 | - | .11 |
| **Crawlspace** | .09 | .16 | .07 | .17 | - | - |

Table 2

Peak Accelerations Recorded at HACH, 17 October 1989

| Floor | SENSOR STACK | | | | |
|---|---|---|---|---|---|
| | Center | | | West | South |
| | N-S | E-W | Vert | N-S | E-W |
| Roof | .64 | .32 | - | .58 | - |
| 7th Flr | .39 | .25 | - | .37 | .46 |
| 6th Flr | .34 | .21 | - | .29 | - |
| 4th Flr | .28 | .19 | - | .21 | - |
| Crawlspace | .13 | .17 | .11 | .10 | .21 |

### Observed Damage to Hospitals

Following the Loma Prieta earthquake, Sacramento District conducted inspections to assess damage to LAMC (along with other selected facilities on the Presidio of San Francisco) and HACH.

In an unpublished report, investigators stated that no structural damage to LAMC was observed. They found a few shear cracks in the walls of a stairway and spalled concrete at the seismic joint at the roof of a second-floor passageway that connects the hospital to the Letterman Army Institute of Research on the east. On the south side of the hospital, spalled concrete was found at the third-floor entrance of the hospital (where the two bottom floors are built below grade). This concrete spalled from the mitered horizontal ledge corners of the precast architectural panels at the fourth through ninth floors.

No structural damage was observed at Hays Hospital.

## 5 CONCLUSION

This report summarizes the data recorded at Letterman Army Medical Center, Presidio of San Francisco, and Hays Army Community Hospital, Fort Ord, from the Loma Prieta Earthquake in California on 17 October 1989. The information is available for use by researchers and analysts studying seismic responses of buildings.

Vertical ground accelerations in the Loma Prieta earthquake measured about one-half to two-thirds the strength of the horizontal ground accelerations, a ratio suggested elsewhere in the literature.[5] Also, vertical motion occurred earlier than horizontal motion in the acceleration time-history and was not in phase with it.

The peak ground accelerations were also in keeping with those recorded at other locations in the San Francisco Bay area and published by USGS and the California Division of Mines and Geology.

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[5] N.M. Newmark and W.J. Hall, *Earthquake Spectra and Design* (University of California-Berkeley Earthquake Engineering Research Institute, 1982).


Figure 1. Seismic instrumentation site locations.

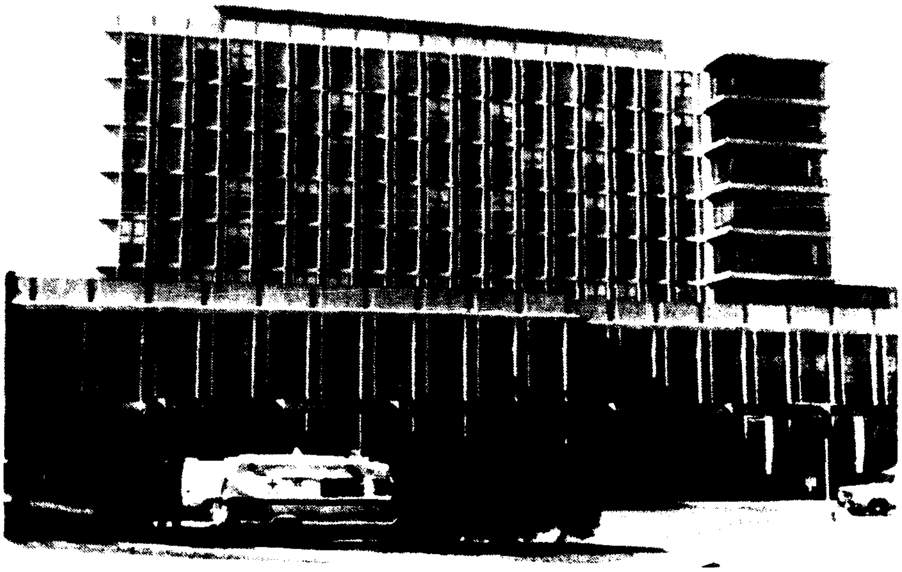
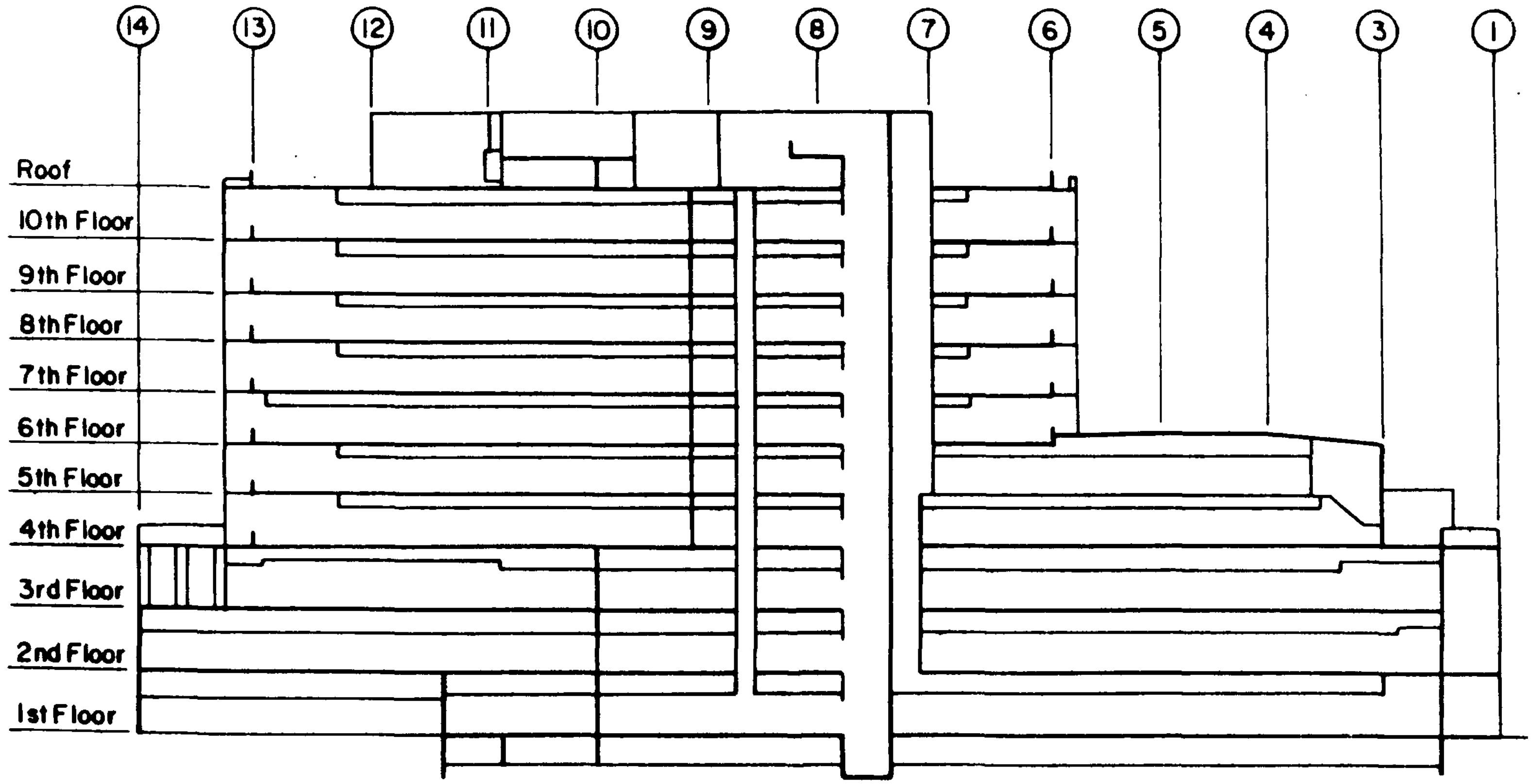


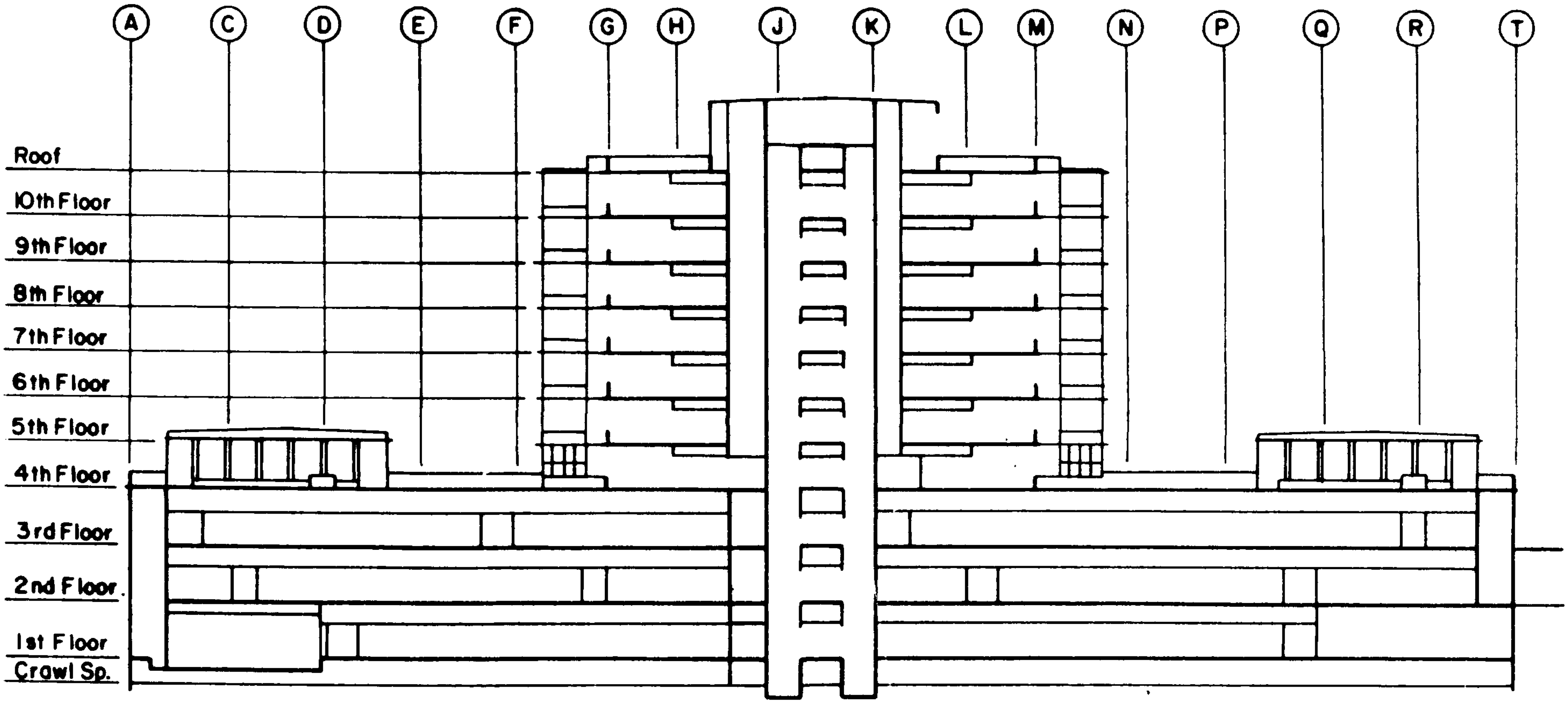
Figure 2. LAMC as viewed from east.

Figure 3. LAMC as viewed from south.




NOTE: Circled numbers at top denote column lines.

Figure 4. LAMC north-south sectional view.




NOTE: Circled letters at top denote column lines.

Figure 5. LAMC east-west sectional view.

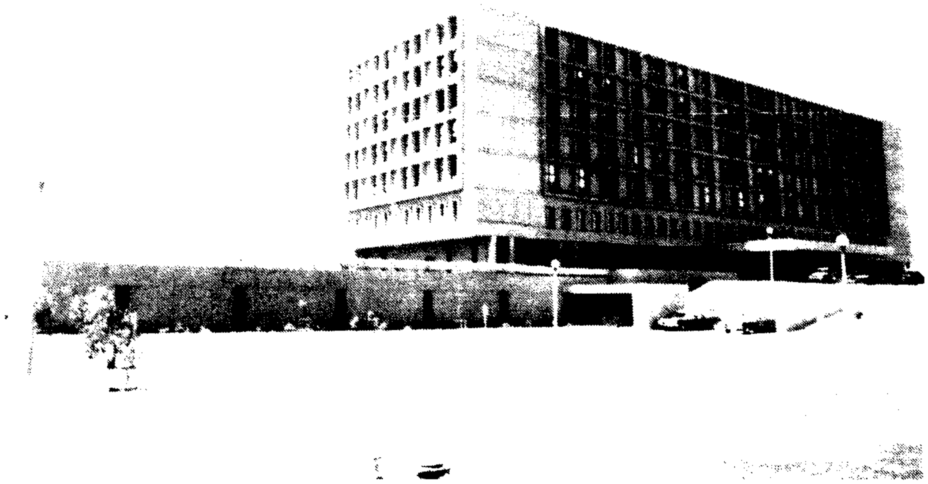


Figure 6. HACH as viewed from north.

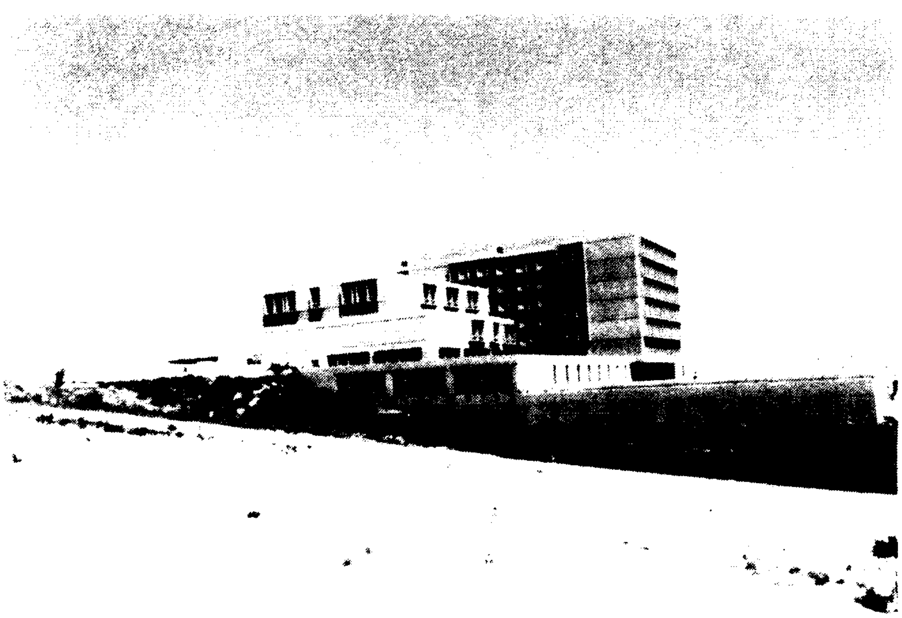
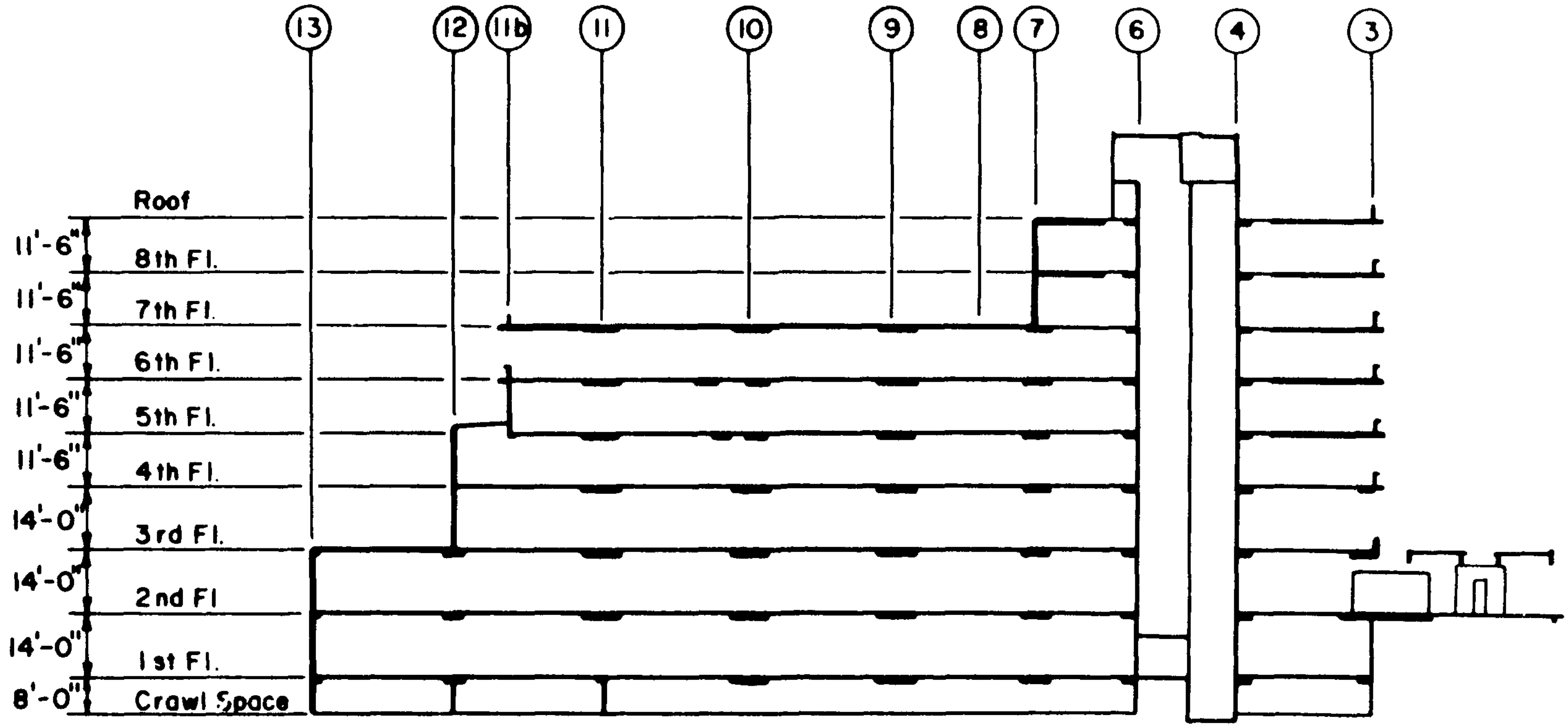
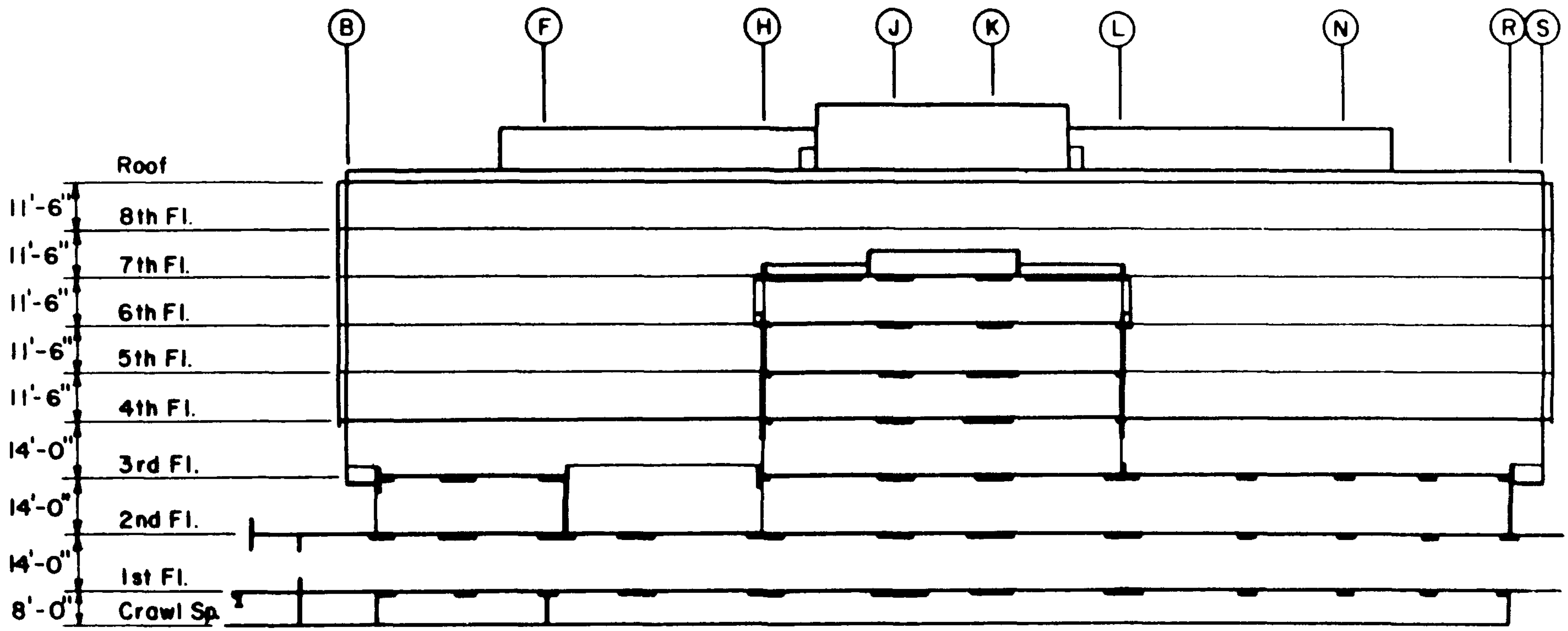


Figure 7. HACH as viewed from southeast.




Note: circled numbers at top denote column lines.

Figure 8. HACH north-south sectional view.




Note: Circled letters at top denote column lines.

**Figure 9. HACH east-west sectional view.**

Figure 10. Digital central recording unit.

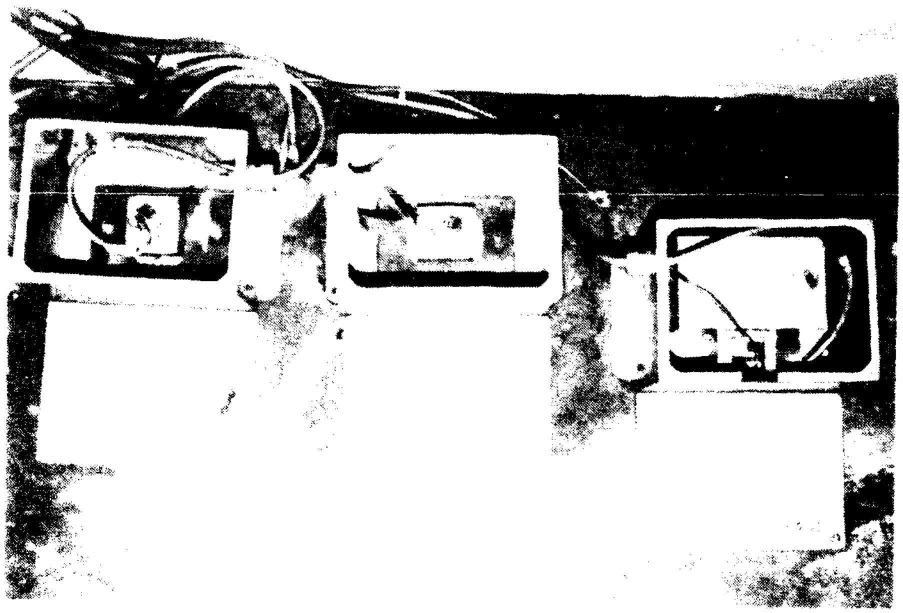


Figure 11. Accelerometers mounted to floor in crawlspace.

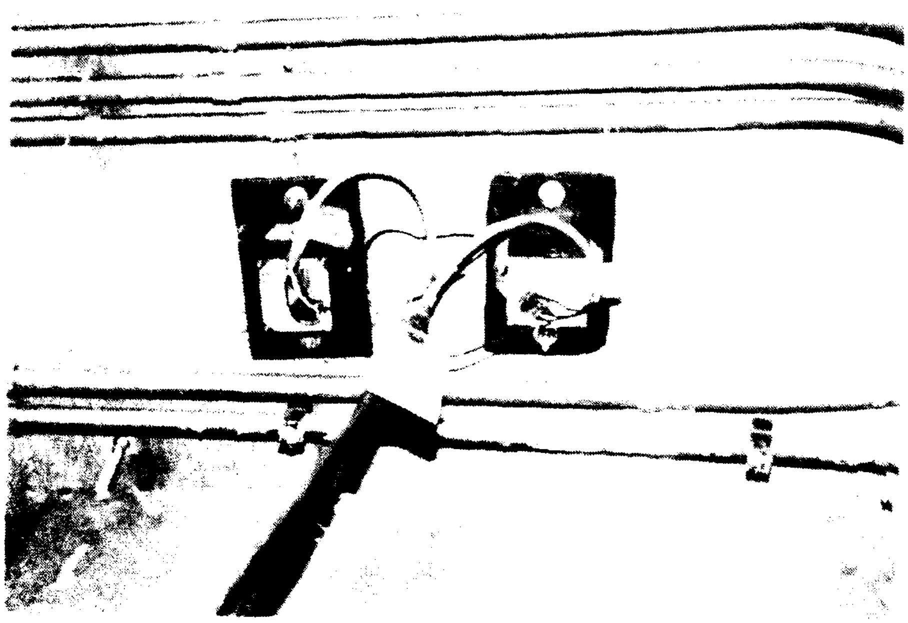


Figure 12. Typical accelerometer mounting on ceiling of upper floors.

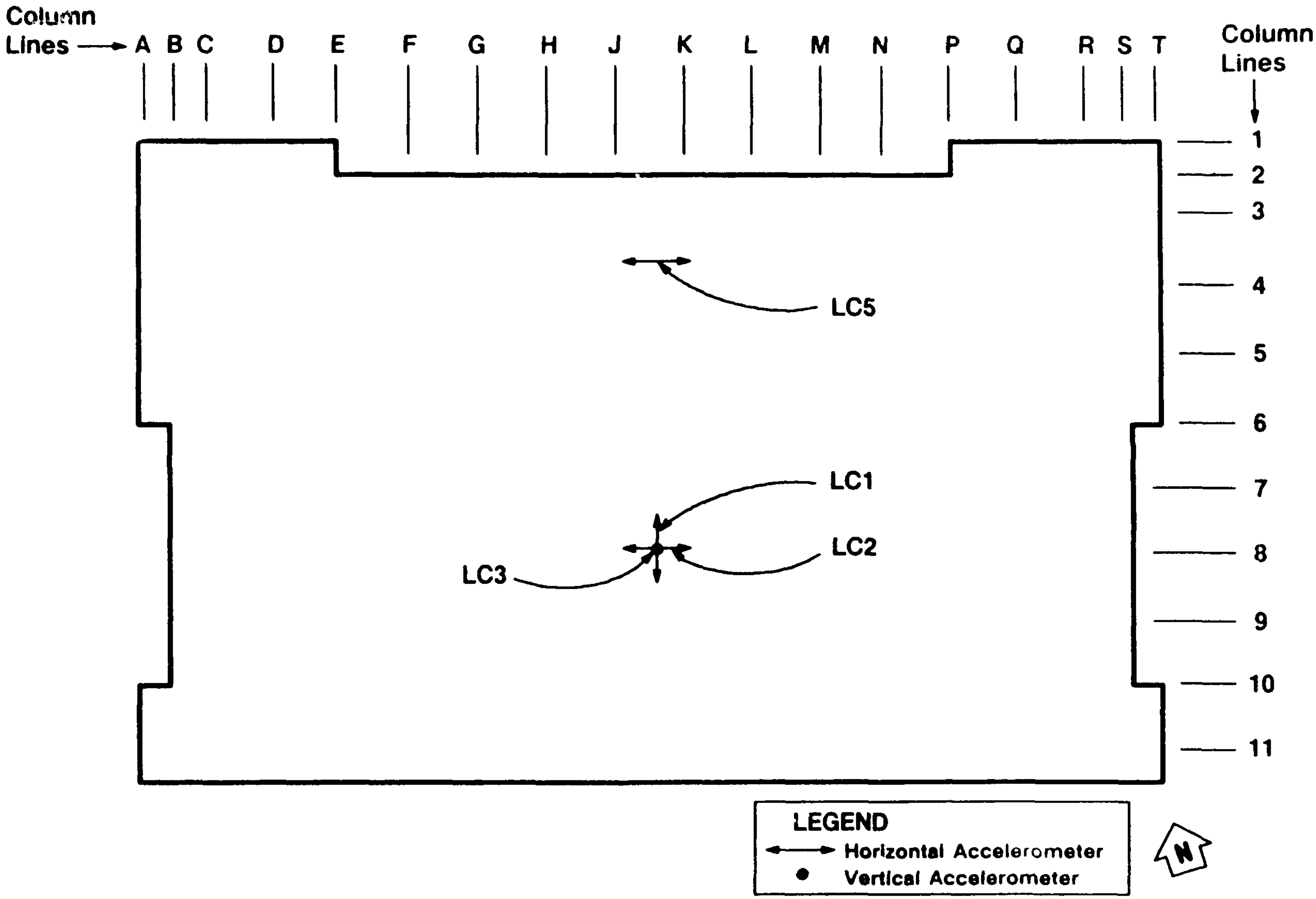



Figure 13. Crawlspace plan, LAMC.

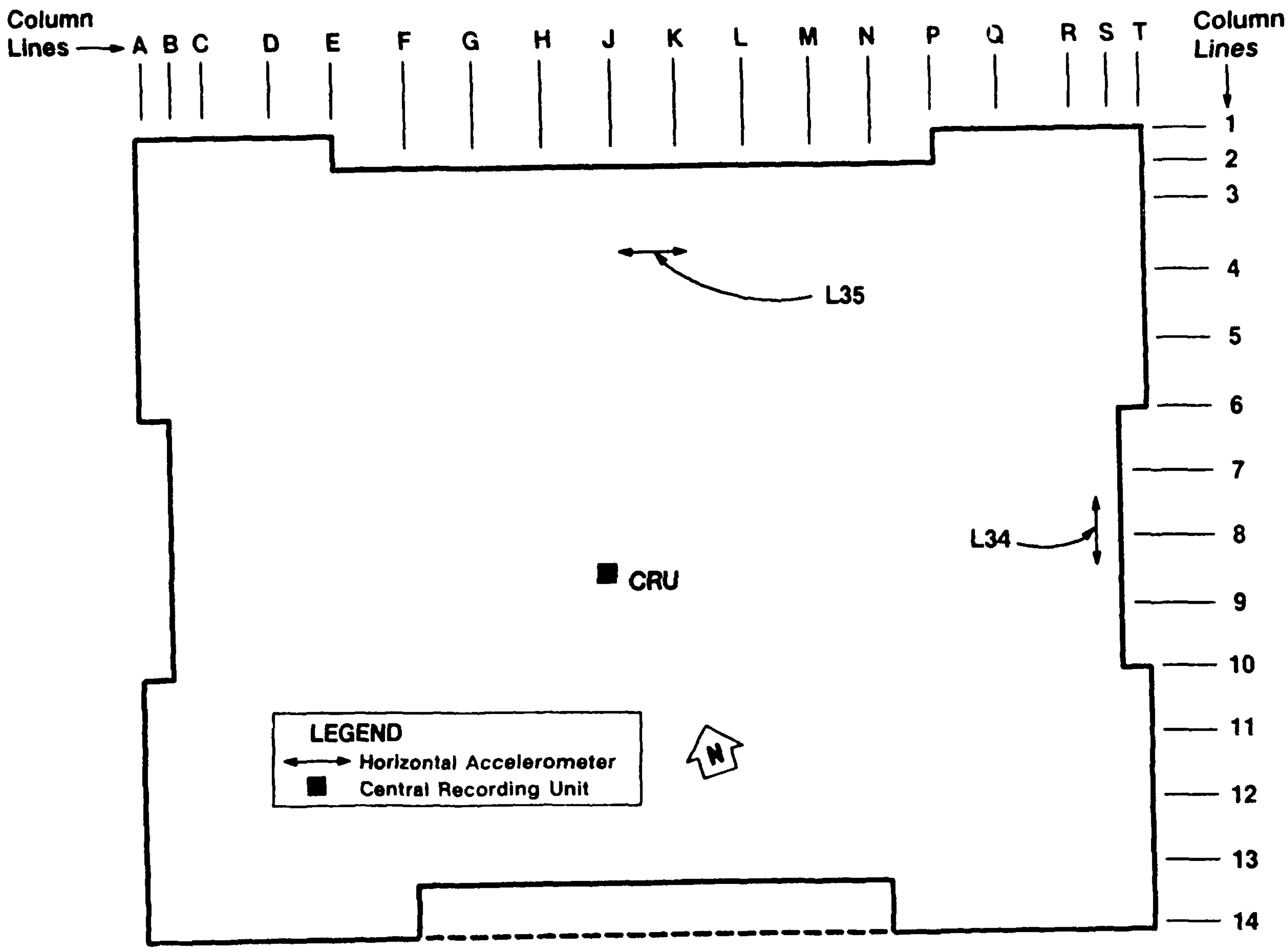



Figure 14. Third-floor plan, LAMC.

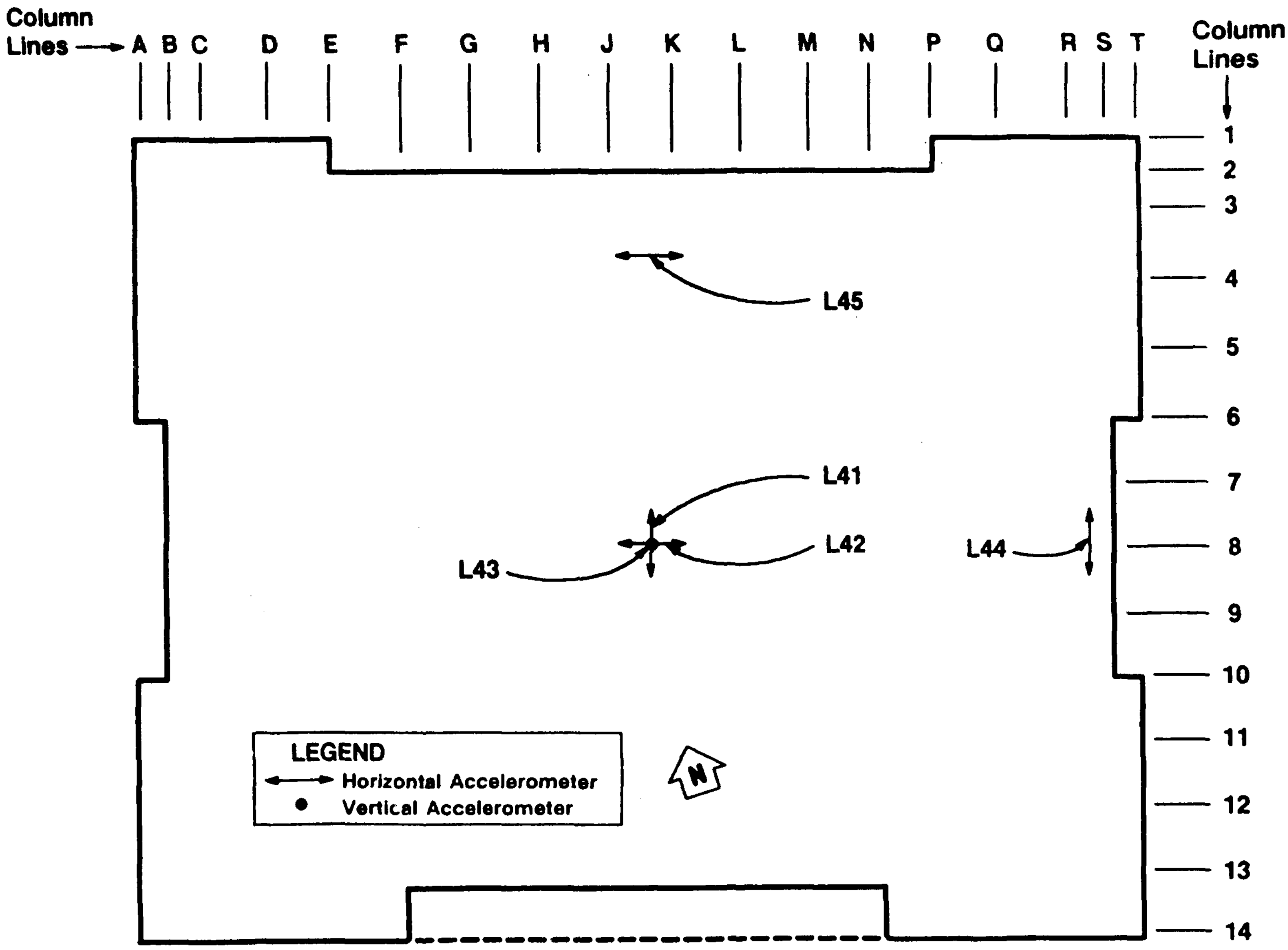



Figure 15. Fourth-floor plan, LAMC.

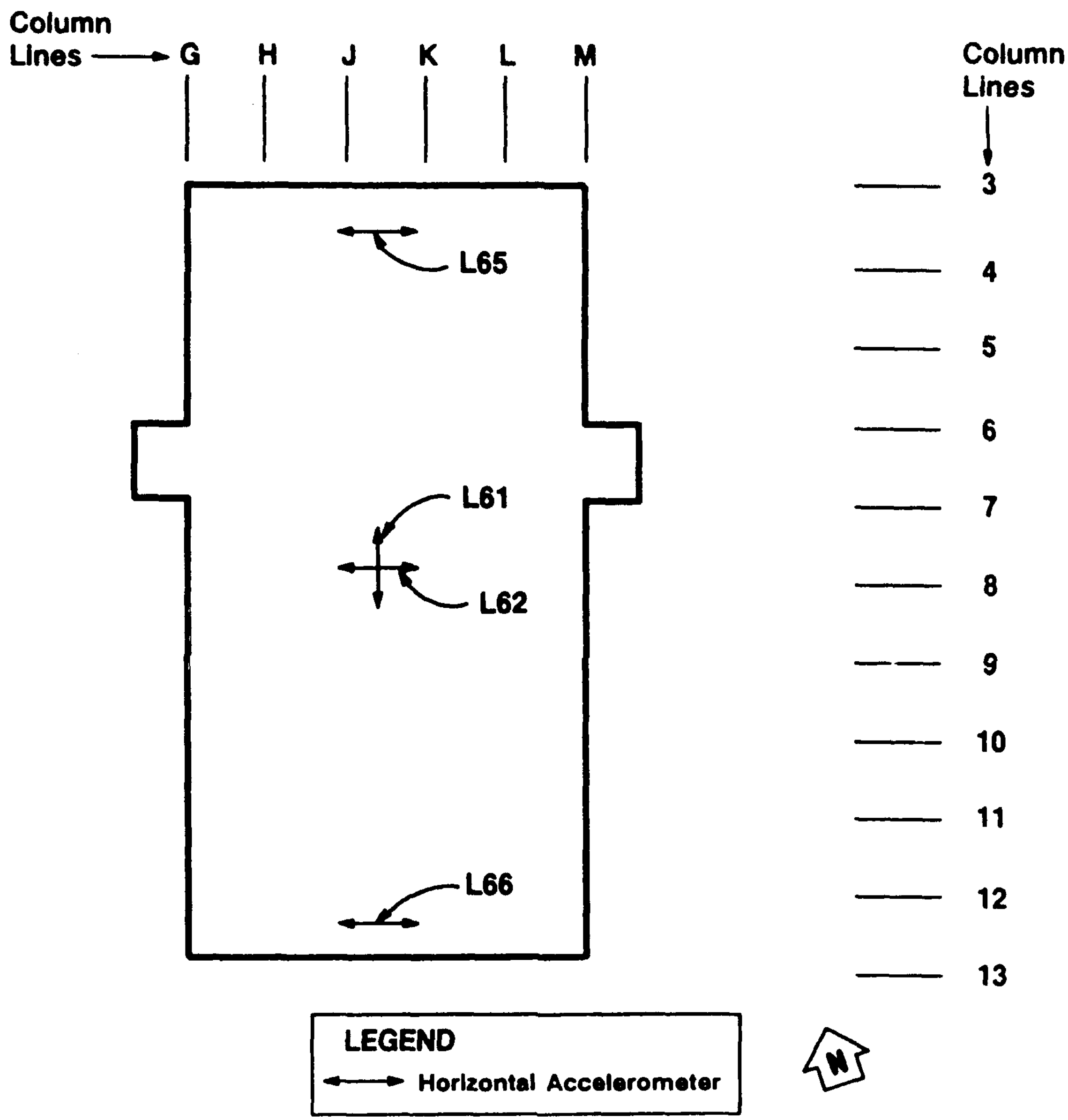



Figure 16. Sixth-floor plan, LAMC.

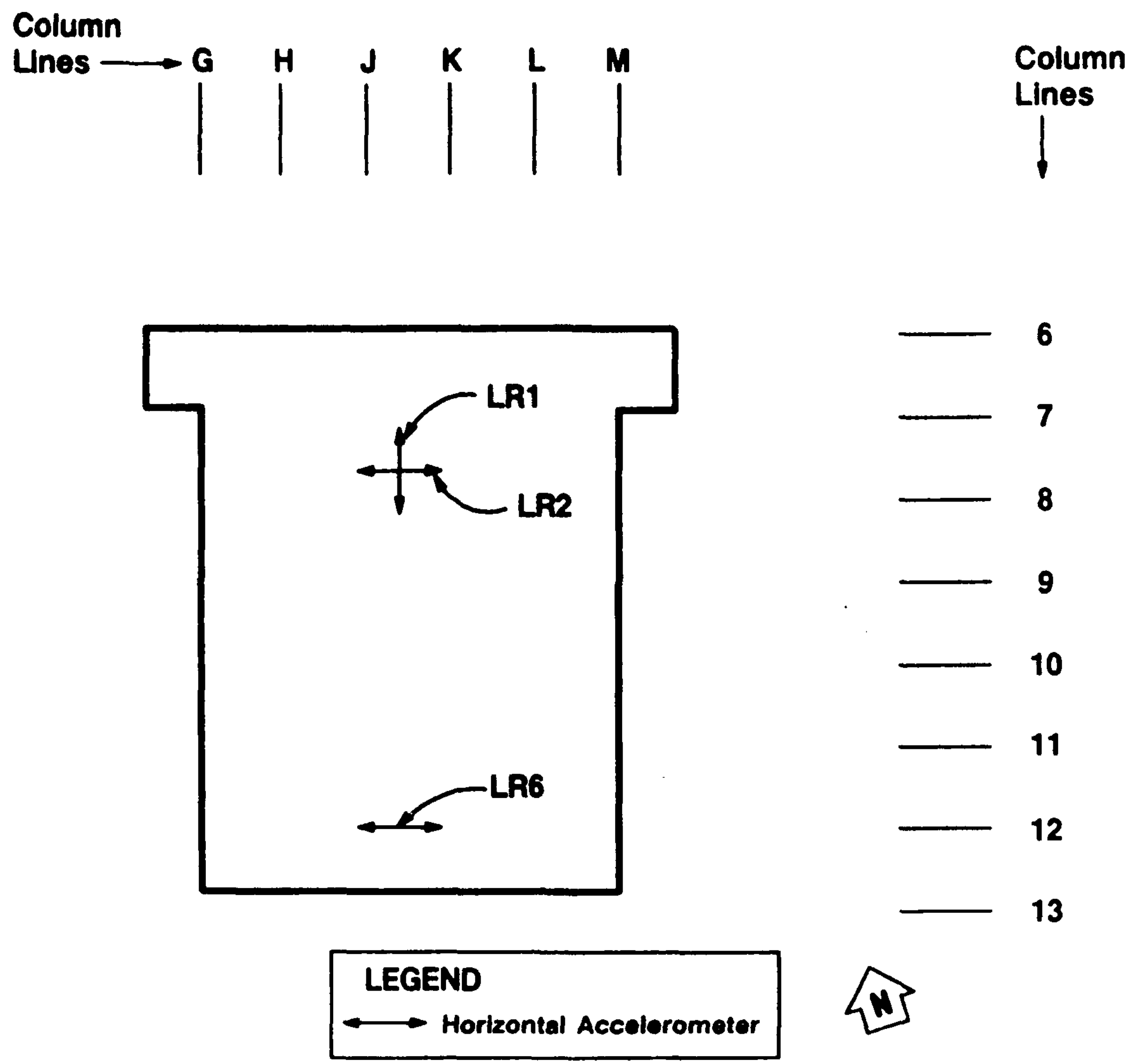



Figure 17. Roof plan, LAMC.

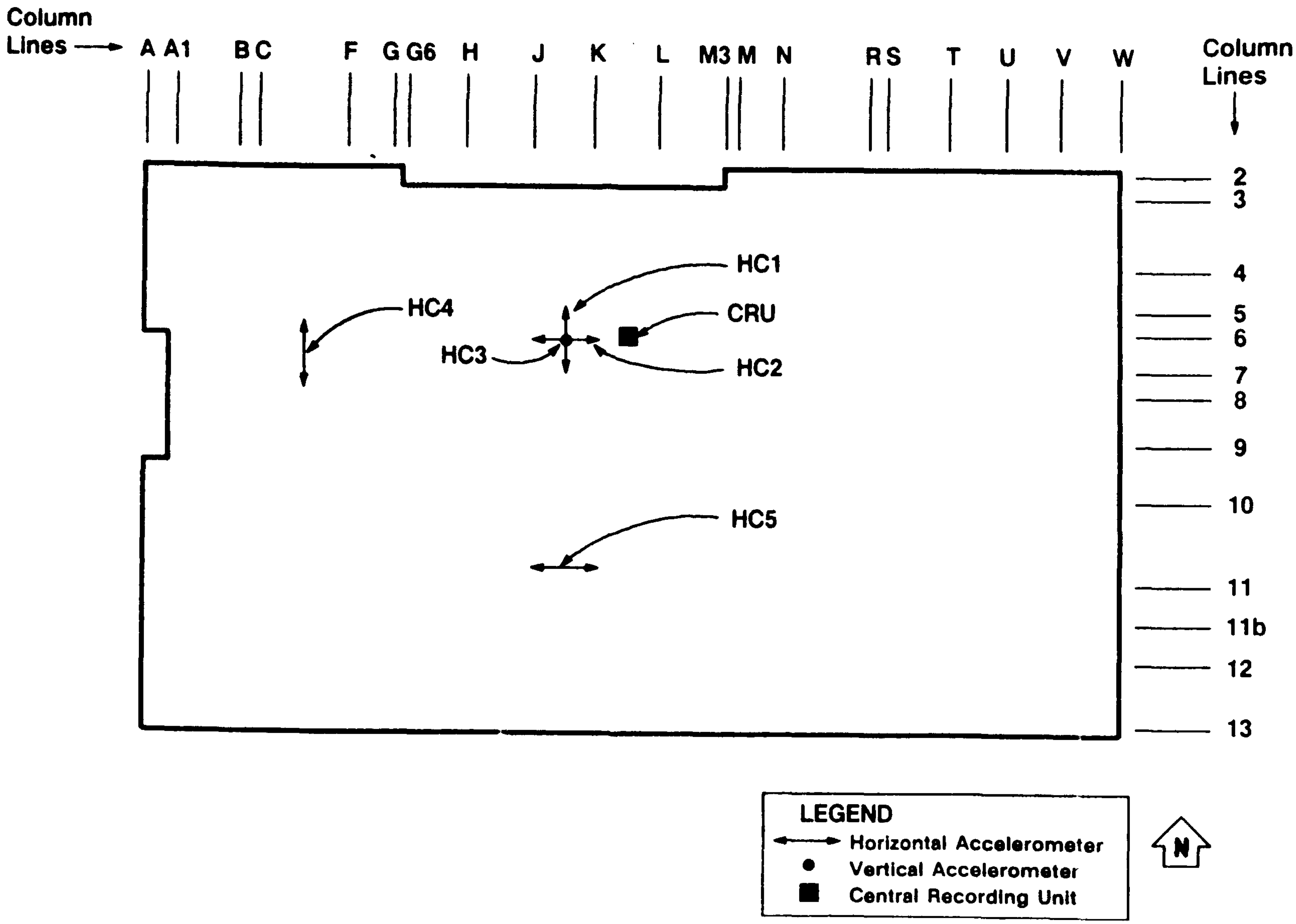



Figure 18. Crawlspace plan, HACH.

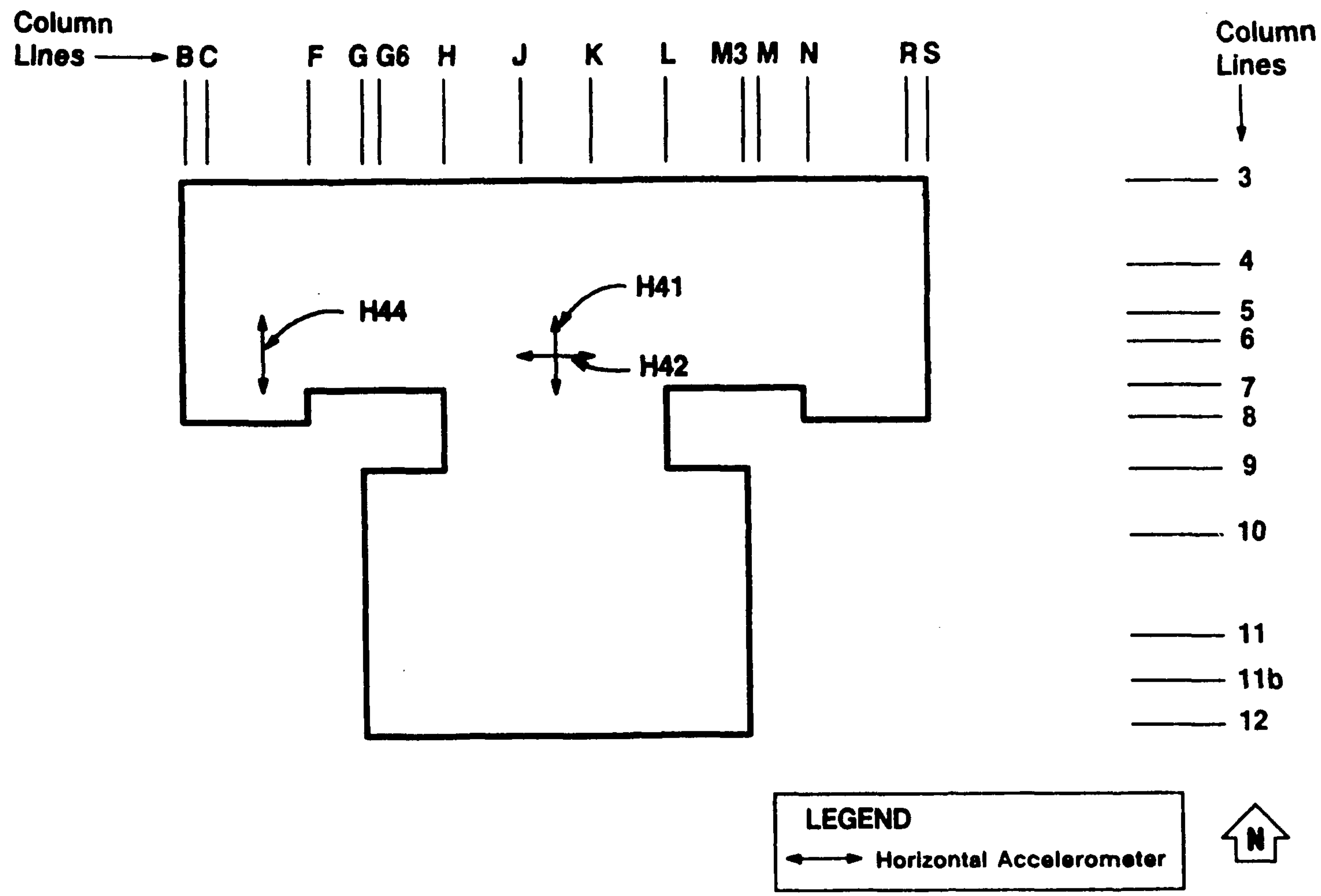



Figure 19. Fourth-floor plan, HACH.

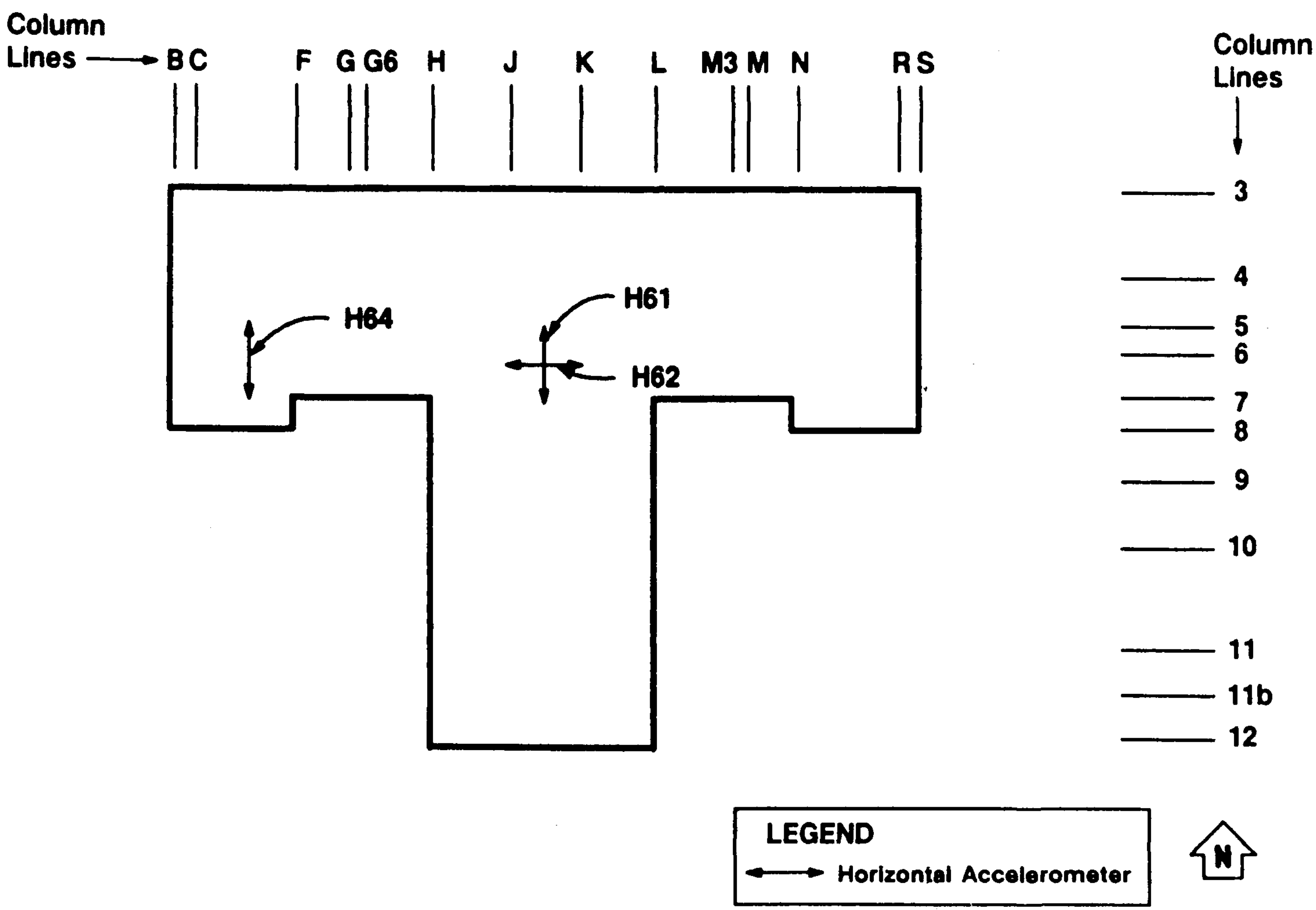



Figure 20. Sixth-floor plan, HACH.

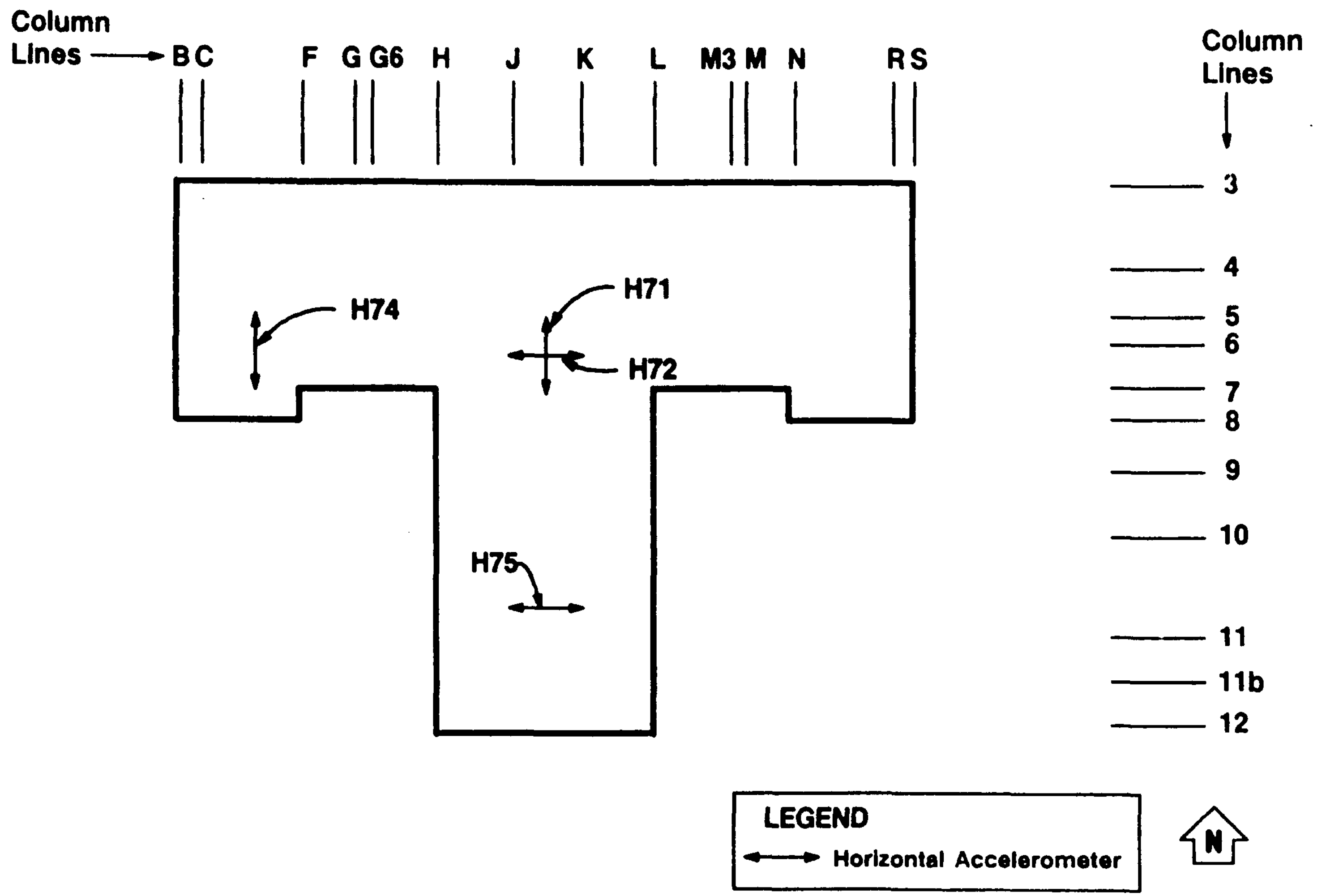



Figure 21. Seventh-floor plan, HACH.

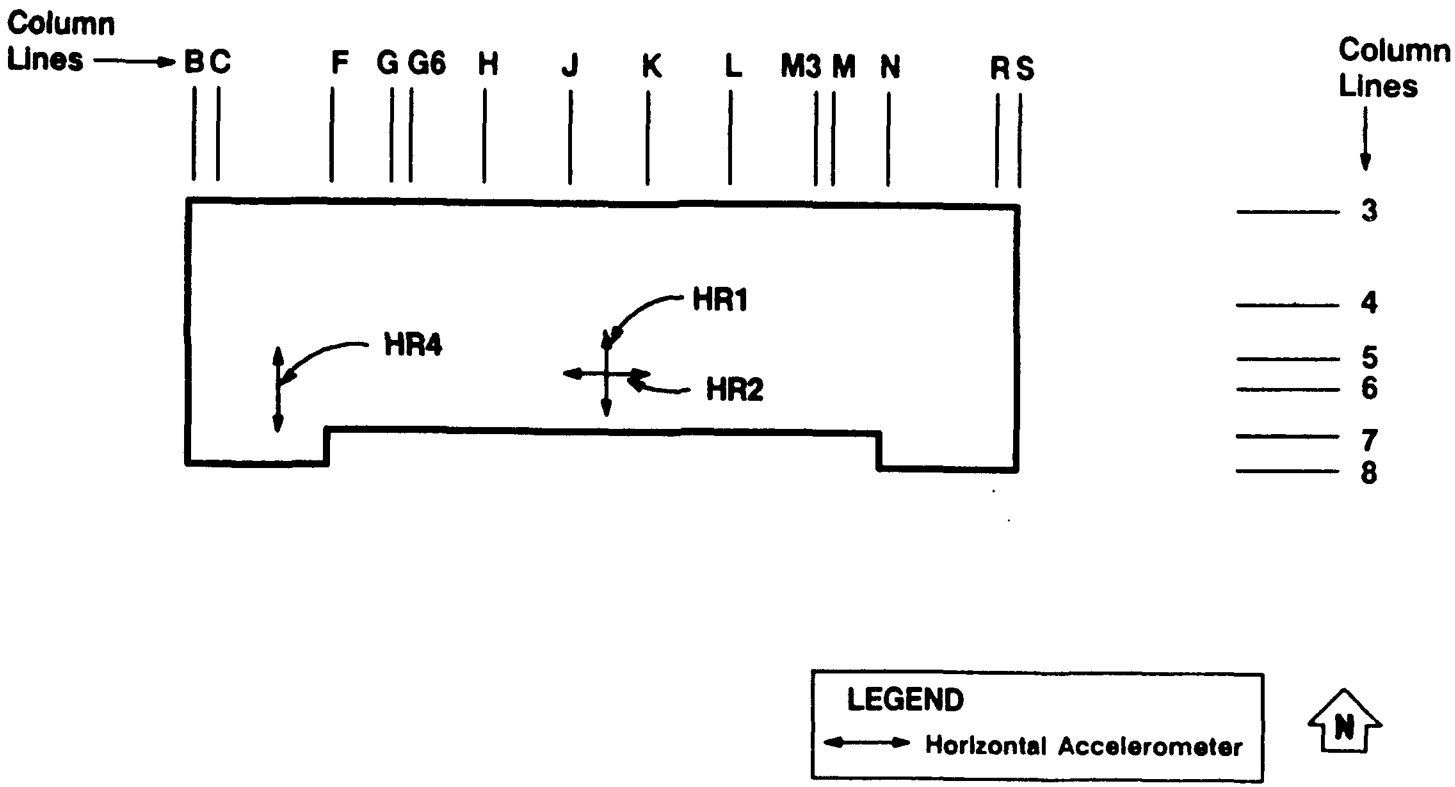
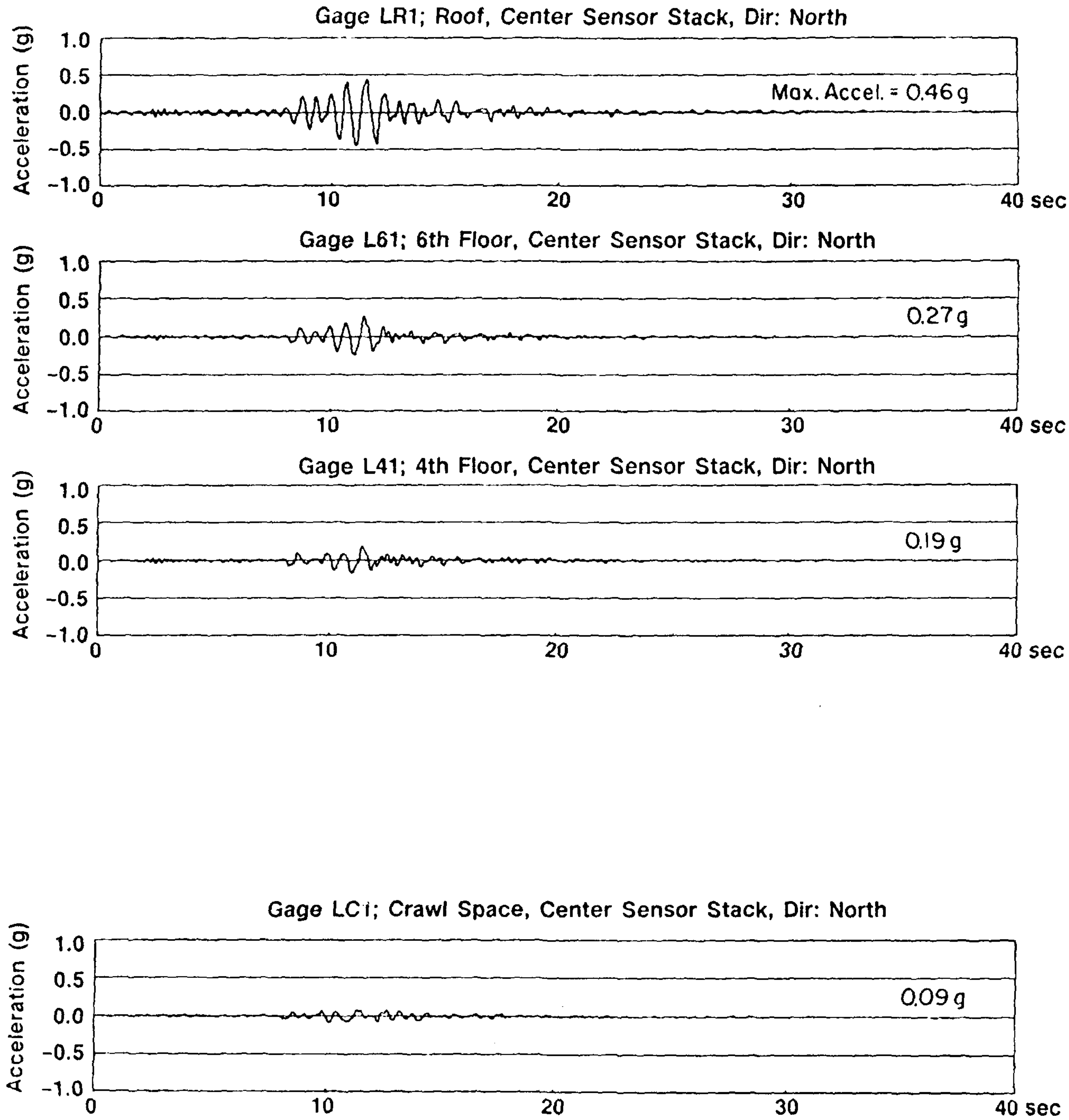
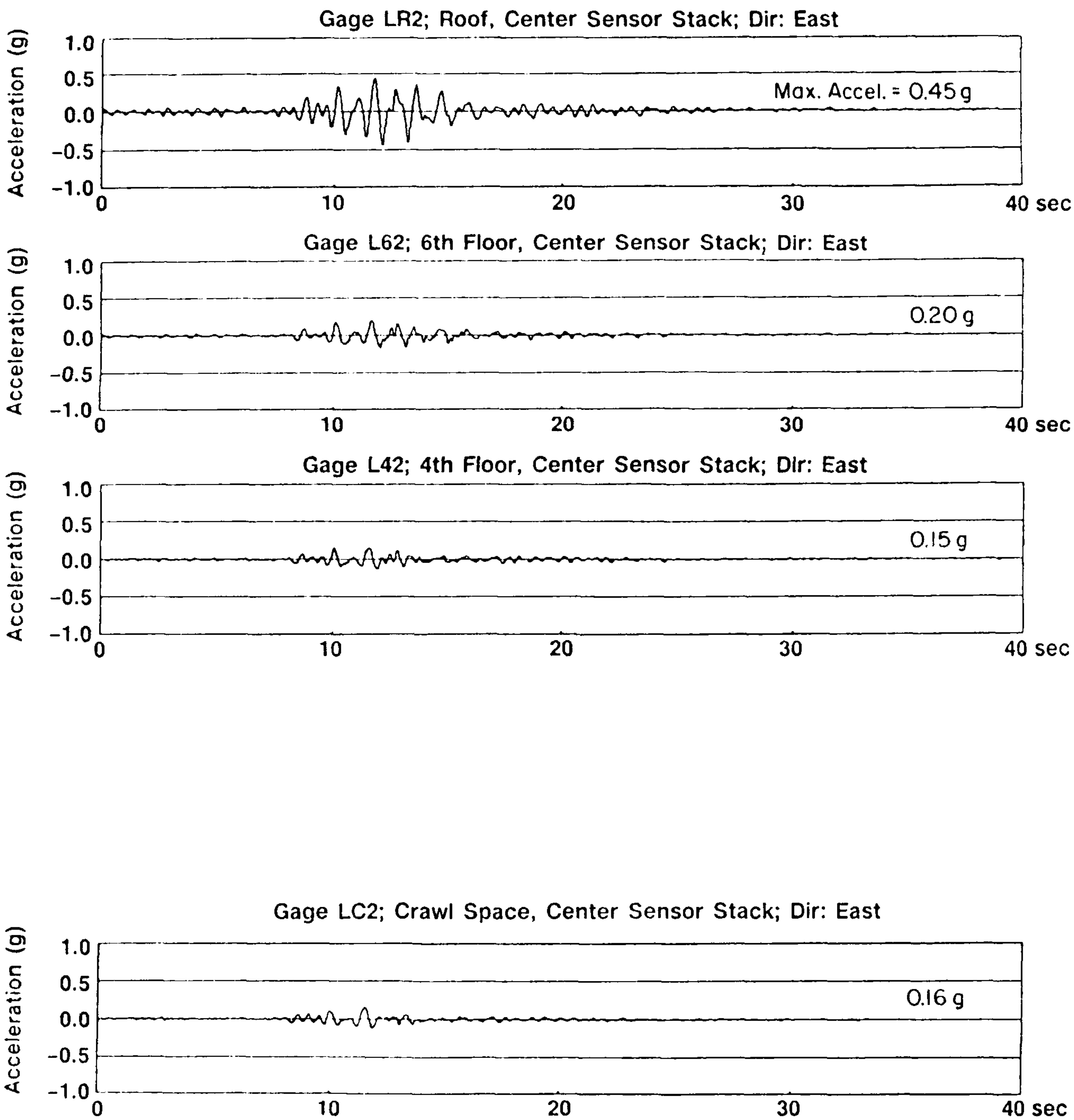



Figure 22. Roof plan, HACH.



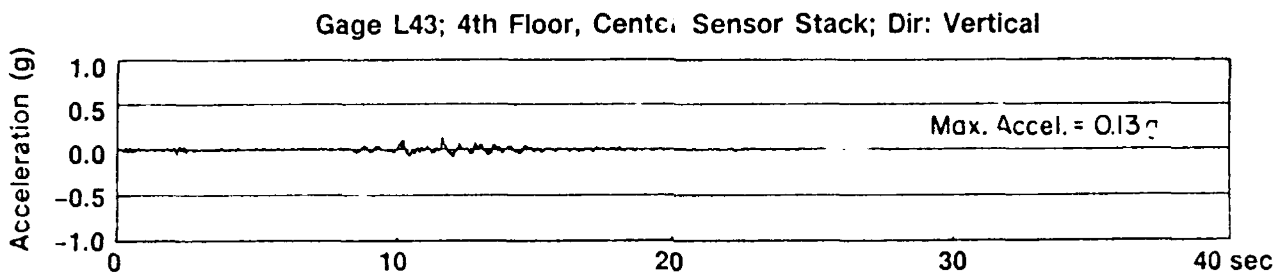

| | |
|---|---|
| Location | 37.799°N, 122.448°W |
| System No. | DCA-300-P18 No. 91 |
| Earthquake | Loma-Prieta, 17 October 1989, 1704 Pacific Standard Time |

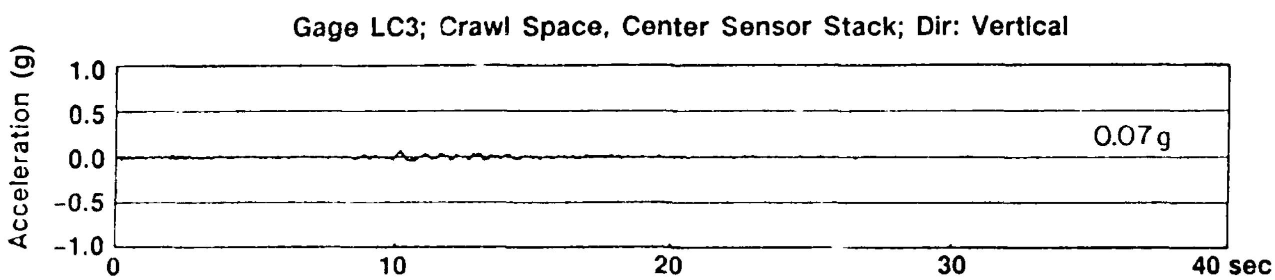
Figure 23. LAMC center sensor stack (north-south horizontal).




| | |
|---|---|
| **Location** | **37.799°N, 122.448°W** |
| **System No.** | **DCA-300-P18 No. 91** |
| **Earthquake** | **Loma-Prieta, 17 October 1989,** |
| | **1704 Pacific Standard Time** |

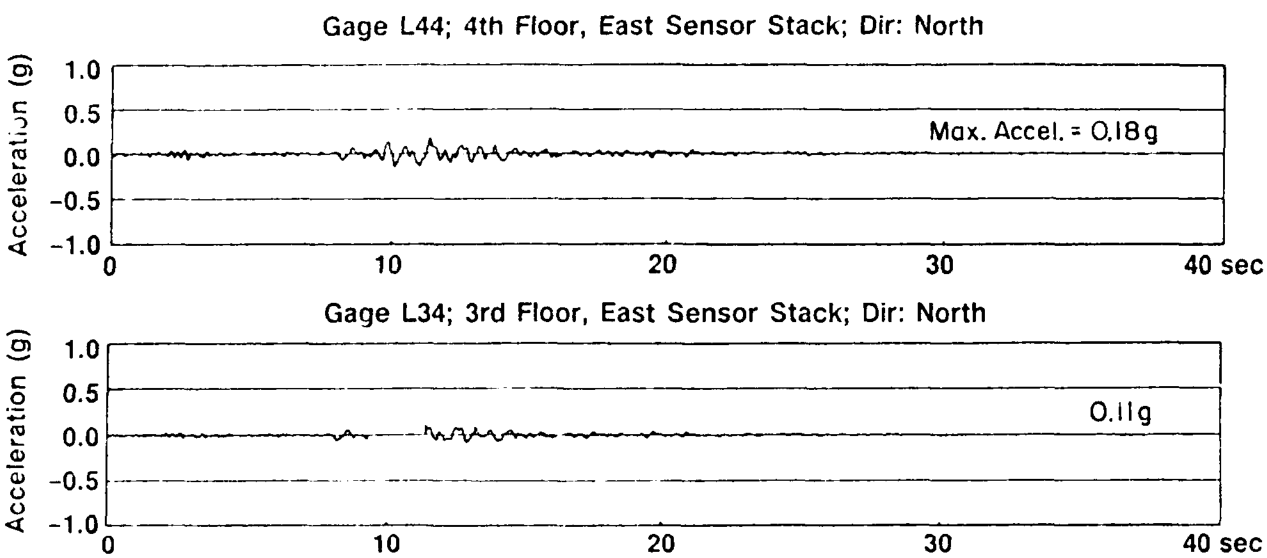
**Figure 24. LAMC center sensor stack (east-west horizontal).**



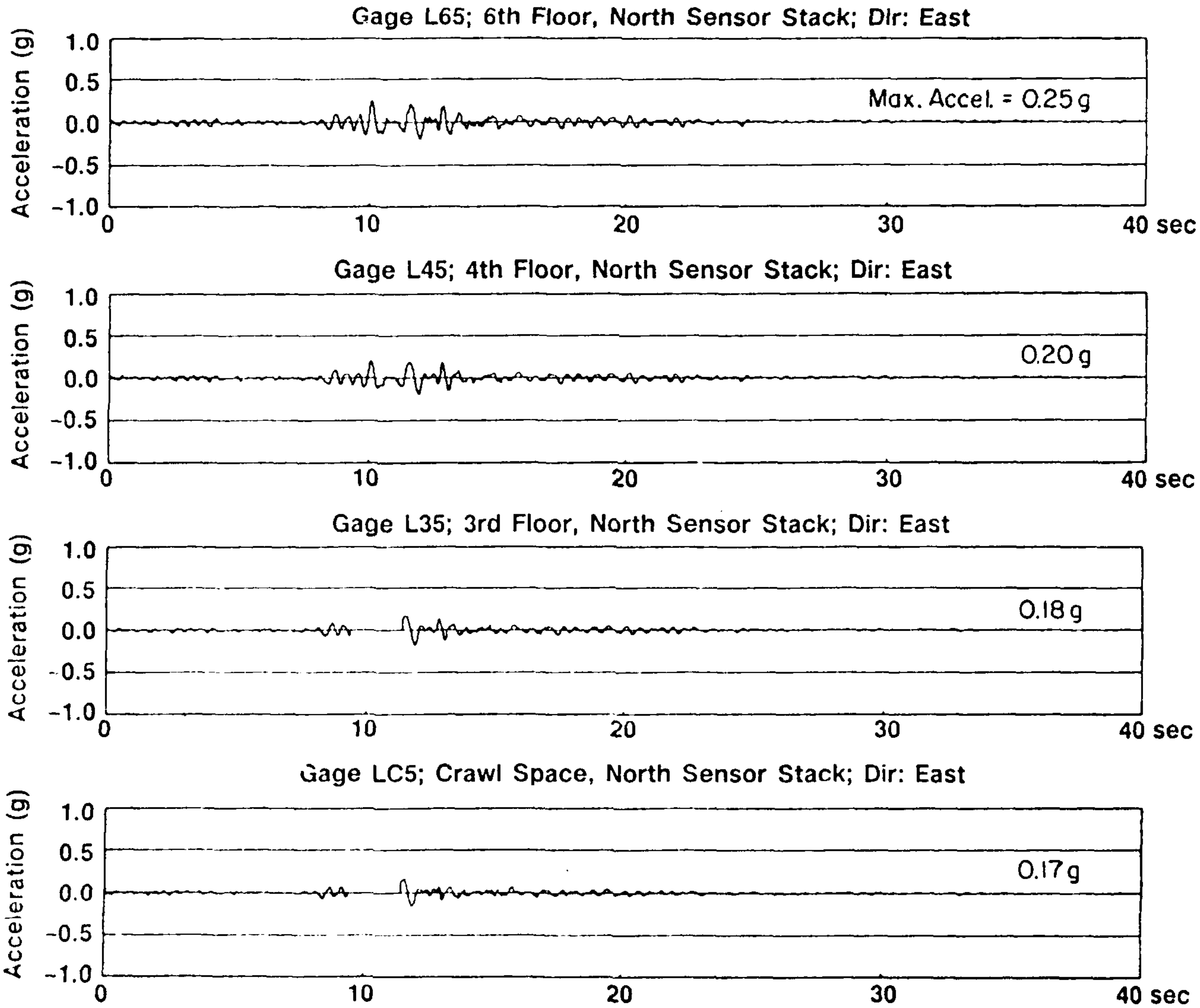

| | |
|---|---|
| **Location** | **37.799°N, 122.448°W** |
| **System No.** | **DCA-300-P18 No. 91** |
| **Earthquake** | **Loma-Prieta, 17 October 1989, 1704 Pacific Standard Time** |

Figure 25. LAMC center sensor stack (vertical).




| | |
|---|---|
| *Location* | 37.799°N, 122.448°W |
| System No. | DCA-300-P18 No. 91 |
| Earthquake | Loma-Prieta, 17 October 1989, 1704 Pacific Standard Time |

Figure 26. LAMC east sensor stack (north-south horizontal).




| | |
|---|---|
| Location | 37.799°N, 122.448°W |
| System No. | DCA-300-P18 No. 91 |
| Earthquake | Loma-Prieta, 17 October 1989, 1704 Pacific Standard Time |

Figure 27. LAMC north sensor stack (east-west horizontal).

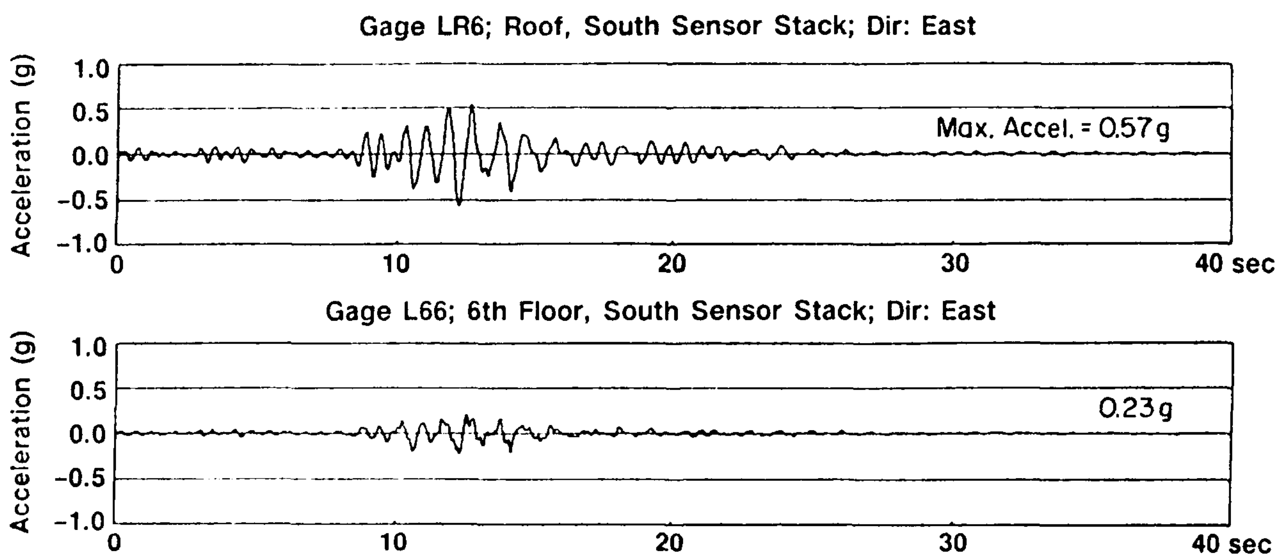
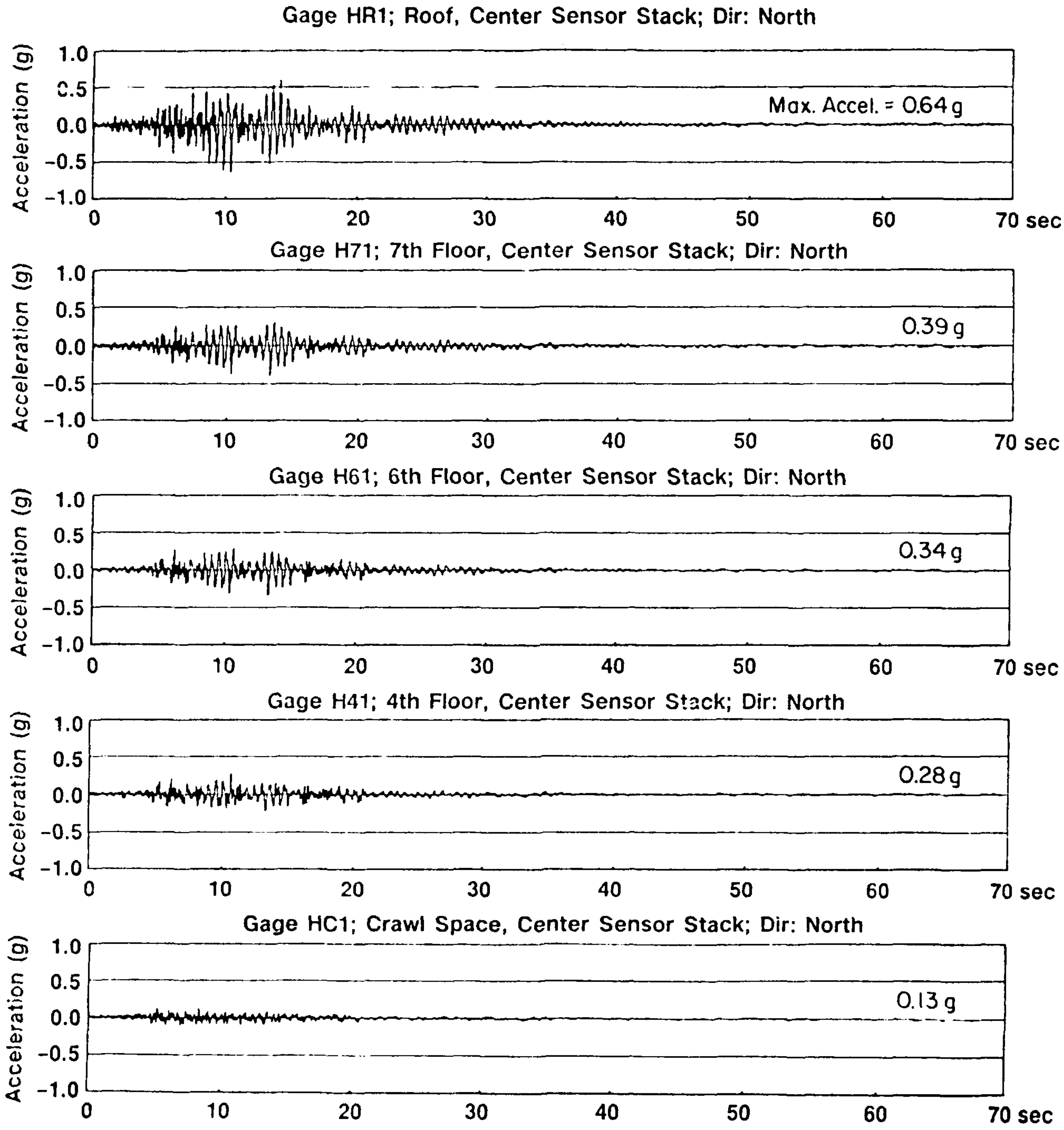
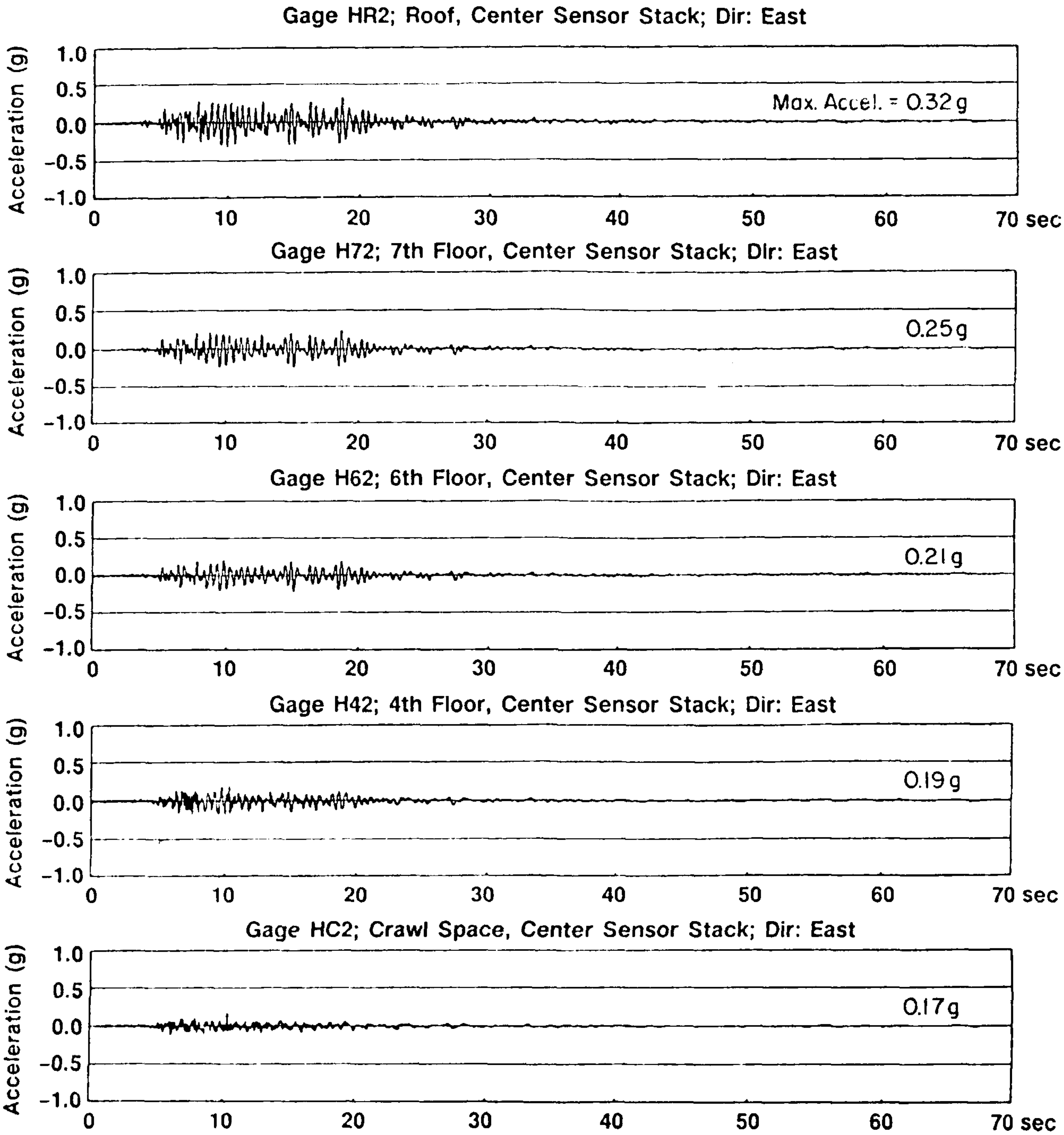



Figure 28. LAMC south sensor stack (east-west horizontal).



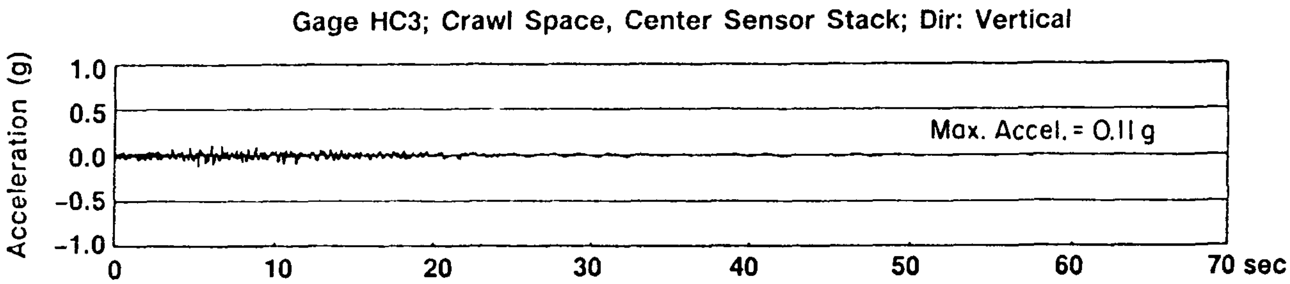

| | |
|---|---|
| Location | 36.641°N, 121.796°W |
| System No. | DCA-300-P18 No. 93 |
| Earthquake | Loma-Prieta, 17 October 1989, 1704 Pacific Standard Time |

Figure 29. HACH center sensor stack (north-south horizontal).



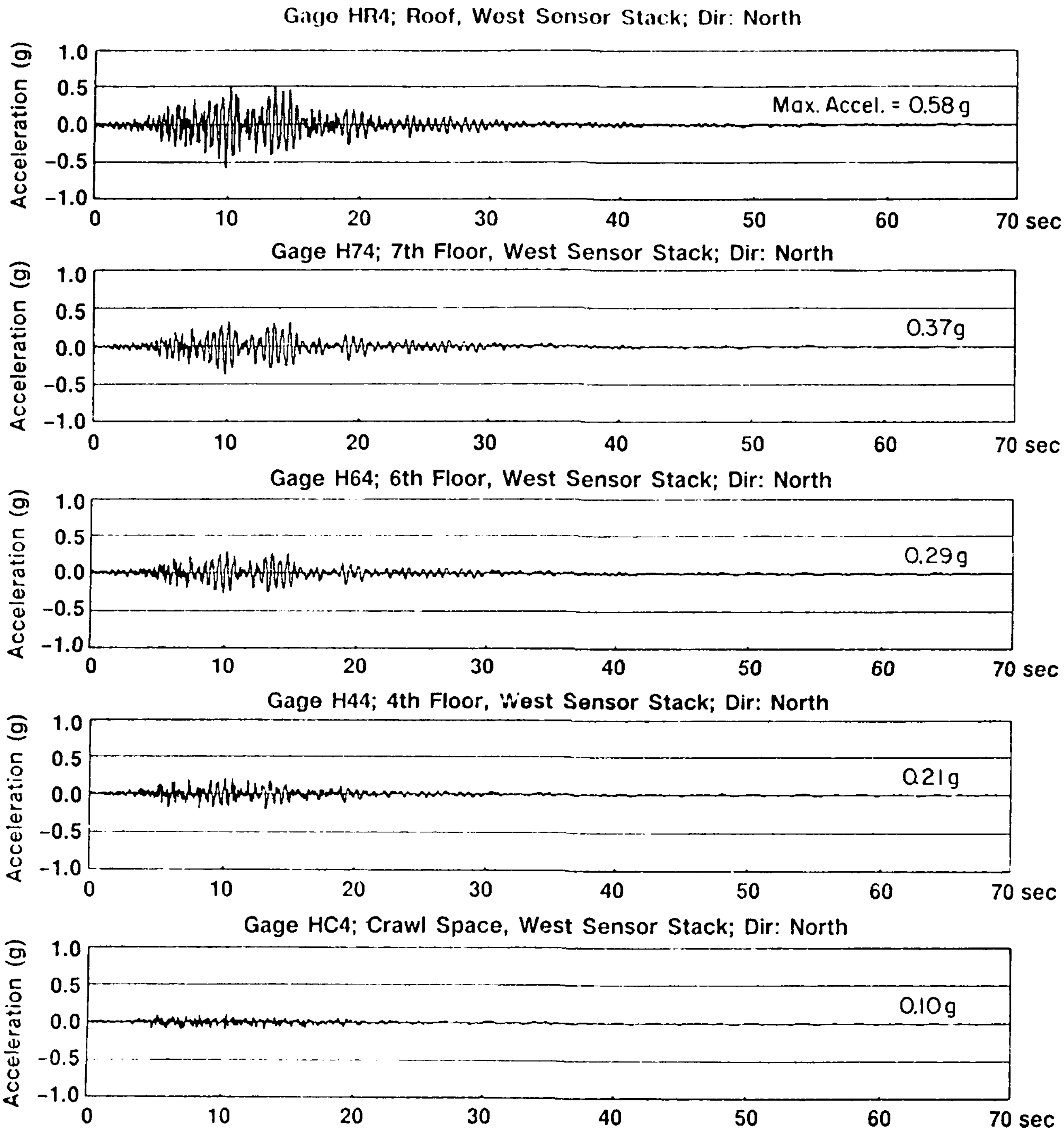

| | |
|---|---|
| Location | 36.641°N, 121.796°W |
| System No. | DCA-300-P18 No. 93 |
| Earthquake | Loma-Prieta, 17 October 1989, 1704 Pacific Standard Time |

Figure 30. HACH center sensor stack (east-west horizontal).




| | |
|---|---|
| Location | 36.641°N, 121.796°W |
| System No. | DCA-300-P18 No. 93 |
| Earthquake | Loma-Prieta, 17 October 1989, 1704 Pacific Standard Time |

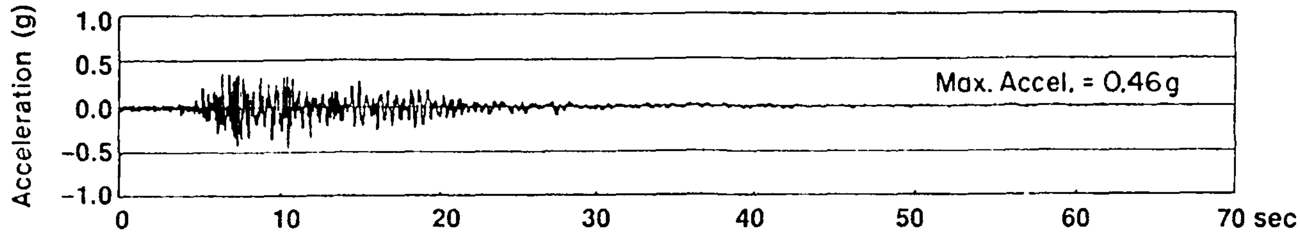
Figure 31. HACH center sensor stack (vertical).



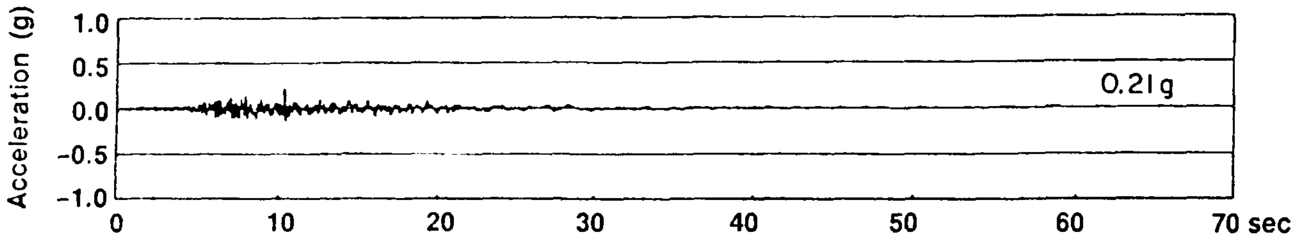

| | |
|---|---|
| Location | 36.641°N, 121.796°W |
| System No. | DCA-300-P18 No. 93 |
| Earthquake | Loma-Prieta, 17 October 1989, 1704 Pacific Standard Time |

Figure 32. HACH west sensor stack (north-south horizontal).

Gage H75; 7th Floor, South Sensor Stack; Dir: East




Gage HC5; Crawl Space, South Sensor Stack; Dir: East




| | |
|---|---|
| **Location** | **36.641°N, 121.796°W** |
| **System No.** | **DCA-300-P18 No. 93** |
| **Earthquake** | **Loma-Prieta, 17 October 1989, 1704 Pacific Standard Time** |

**Figure 33. HACH south sensor stack (east-west).**

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63
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